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TECHNICAL MEMORANDUM

SX-523

for the

Federal Aviation Agency

SUMMARY OF V-G AND VGH DATA COLLECTED ON LOCKHEED ELECTRA AIRPLANES DURING AIRLINE OPERATIONS

By Joseph W. Jewel, Jr., and Mary W. Fetner

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

Data indicate that the accelerations caused by gusts and maneuvers are comparable to corresponding accelerations experienced by past piston-engine transports. Placard speeds were exceeded more frequently in the operation of the Electra airplane than in operations involving piston transports. Landing accelerations appear to be somewhat higher than the accelerations for past operations.

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SUMMARY

Data obtained by NASA VGH and V-G recorders on several Lockheed Electra airplanes operated over three domestic routes have been analyzed to determine the in-flight accelerations, airspeed practices, and landing accelerations experienced by this particular airplane. The results indicate that the accelerations caused by gusts and maneuvers are comparable to corresponding results for piston-engine transport airplanes. Oscillatory accelerations (apparently caused by the autopilot or control system) appear to occur about one-tenth as frequently as accelerations due to gusts. Airspeed operating practices in rough air generally follow the trends shown by piston-engine transports in that there is no significant difference between the average airspeed in rough or smooth air. Placard speeds were exceeded more frequently by the Electra airplane than by piston-engine transport airplanes. Generally, the landing-impact accelerations were higher than those for piston-engine transports.

INTRODUCTION

The National Aeronautics and Space Administration has for a number of years collected data on the accelerations or loads experienced, the airspeed practices, and the operating altitudes of transport airplanes during routine airline operations. These data have provided a means of assessing the adequacy of the concepts and criteria used in design of the airplanes and, also, furnished a body of information for use in establishing design requirements for future airplanes. Reference 1 summarizes operational data collected on a number of piston-engine airplanes and reference 2 presents results for a turbine-powered airplane.

As part of the continuing data collection program, V-G and VGH records on several Lockheed Electra airplanes have been collected during operations on three airlines since 1959. As the evaluation of these records progressed, the data obtained have been made available to the manufacturer and to government organizations for use in investigations of the airplane. In this report the V-G and VGH data available to date from these airplanes are summarized. These data pertain to the airspeed operating practices, operating altitudes, gust and maneuver accelerations, airplane- or autopilot-induced oscillatory accelerations, landing-impact accelerations, vertical velocity at landing, and the gust velocities encountered.

SYMBOLS

W	design gross weight of airplane, lb
S	wing area, sq ft
A	aspect ratio
b	wing span, ft
$\bar{c}$	mean geometric chord, ft
g	acceleration due to gravity, ft/sec^2
V_{NO}	placard normal operating speed, knots
V_{NE}	placard never-exceed speed, knots
U_{de}	derived gust velocity, ft/sec
a_n	normal acceleration, g units
K_g	gust factor
ρ_o	air density at sea level, slugs/cu ft
V_e	equivalent airspeed, ft/sec
M	Mach number
μ_g	mass ratio of airplane
V_{max}	maximum indicated airspeed, knots

M_{NO} normal operating Mach number

M_{NE} never-exceed Mach number

m slope of lift curve per radian

INSTRUMENTATION AND AIRPLANE

The data were obtained from NASA VGH and V-G recorders which are described in references 3 and 4, respectively. The VGH recorder yields a time-history record of indicated airspeed, pressure altitude, and normal acceleration as shown by the typical record in figure 1. The accelerometers were mounted on the center line of the airplane at fuselage station 559 and water line station 89. This location is approximately 3 feet forward of the center of gravity. The recorder base was installed in the radio equipment area. Pressures for the airspeed and altitude recordings were obtained from the copilot pitot line and the autopilot static line. The V-G recorder yields an envelope-type record of the maximum accelerations experienced at various indicated airspeeds. A typical V-G record is shown in figure 1. This recorder was mounted on the center line of the airplane at fuselage station 565 and water line station 111 and, thus, was about $2\frac{1}{2}$ feet forward of the center of gravity. Recorded airspeeds were obtained from the copilots' pitot tube and the alternate static tube.

Some of the characteristics of the airplane that are pertinent to the evaluation of the data are given in the following table:

Design gross weight, W, lb	113,000
Wing area, S, sq ft	1,300
Aspect ratio, A	7.5
Span, b, ft	99
Mean geometric chord, $\bar{c}$, ft	13.25

The operational placard speeds for which the airplane was originally certificated are shown by the solid curves in figure 2. Reduced speed placards were placed on the airplane on March 27, 1960, and these placards are shown by the dashed curves in the figure.

SCOPE OF DATA

VGH data were available from six airplanes operated on domestic routes by three airlines, hereafter referred to as airlines A, B, and C.

The general routes from which the data were collected are shown in figure 3, and the distribution of the VGH record hours by year and month is given in figure 4. As shown in figure 4, the data cover operations prior to the restrictions being placed on the airplane on March 27, 1960. Additional data have been collected subsequent to this data, but only limited reference to the later data will be made.

The sizes of the VGH data samples from each airline are summarized in table I in terms of the total number of flight hours that were available for evaluation. As shown in the table, the overall data sample sizes were approximately 1,164 hours for airline A, 893 hours for airline B, and 192 hours for airline C. Because of the relatively small amount of data from airline C, only limited results from this data sample will be presented. Inasmuch as the total record samples from airlines A and B either were not required in certain phases of the analysis or because record evaluation for some phases has not been completed, the results to be presented were not in all cases based on the total sample sizes available. In order to indicate the actual sample sizes used, therefore, table I gives the number of flight hours or number of flights from which the results were obtained.

The V-G data sample collected from four airplanes operated by airline A consisted of eight V-G records representing an estimated 1,711 flight hours between September 1959 and March 1960.

EVALUATION OF RECORDS

VGH Records

The VGH records were evaluated to obtain information on the gust and maneuver accelerations, airplane- or autopilot-induced oscillatory accelerations, landing-impact accelerations, airspeed operating practices, and the operational altitudes. For this purpose, each flight on the VGH record was classified as being either a routine passenger-carrying operational flight, or a check flight for pilot training or airplane testing.

The operational flights were divided into three segments; climb, cruise, and descent, as illustrated in figure 1. The climb condition covered the time from take-off until the airplane began to maintain level flight consistently; the cruise covered the essentially constant altitude portion of the flight; and the descent, the portion of flight from the end of cruise until the airplane landed. Both the climb and descent flight conditions occasionally included short periods when the airplane was in level flight while holding altitude as a result of operational or air traffic control procedures. Also, the cruise condition occasionally included periods when the airplane was climbing or descending to a different cruise altitude.

Accelerations

The accelerations on each operational flight were classed as resulting from either gusts or maneuvers on the basis of the criteria described in reference 5. The peak values of each gust acceleration greater than ±0.2g and of each maneuver acceleration greater than ±0.1g were read by using the 1 g steady-flight position of the acceleration trace as the reference. For each gust acceleration, the corresponding simultaneous values of airspeed and altitude were also evaluated.

The check flights were evaluated only for maneuver accelerations which were read to a threshold of ±0.1g.

The initial landing-impact accelerations experienced during operational and check flights were read and tabulated in 0.1g class intervals. These accelerations were identified on the records by the impulse-like characteristics of the trace at the instant of landing impact. The probability distributions of landing-impact accelerations were used to estimate the probability distribution of vertical velocities at landing. A value of 0.208 feet per second per g was used for converting accelerations to vertical velocities and was obtained from the empirically derived relationship based on airplane empty weight given in reference 6.

The VGH records collected prior to March 1960 contained oscillatory motions as evidenced by deflections of the acceleration trace and, to a lesser extent, by the airspeed and altitude traces. For the most part, the accelerations associated with these oscillations were relatively constant in amplitude (generally ±0.3g) and frequency (about 6 to 10 cycles per minute) during any particular occurrence (fig. 5(a)). Occasionally, however, the oscillations tended to become convergent (fig. 5(b)) or divergent (fig. 5(c)). The oscillatory acceleration peaks were not individually read but, rather, an estimate of the distribution of these accelerations was obtained from measurements of the average peak amplitude, frequency, and time duration of each continuous occurrence of oscillations greater than ±0.06g. In addition, the airspeed and altitude associated with each oscillatory occurrence was read.

Airspeeds and Altitudes

Distributions of airspeed and altitude for the operational flights were obtained by reading the indicated airspeed and pressure altitude for each 1-minute period of flight. The airspeed data were sorted according to whether the airplane was in rough or smooth air. For this purpose, the airplane was assumed to be in rough air whenever gust accelerations greater than about ±0.1g were experienced. This procedure is consistent with that followed in past analyses of VGH-type data. (See ref. 2, for example.)

In addition to the evaluation of airspeeds at 1-minute intervals, a more detailed evaluation was made of the occurrence of speeds in excess of the placard speeds. This evaluation consisted of determining the maximum speed and the altitude associated with each exceedence of the placard speed V_{NO} $\left(\text{or } M_{NO}\right)$. (See fig. 2.) Also, the time flown at speeds higher than V_{NO} $\left(\text{or } M_{NO}\right)$ was evaluated.

Gust Velocities

Gust accelerations and the corresponding altitudes and airspeeds were used to calculate gust velocities by means of the derived gust velocity equation described in reference 7:

$$U_{de} = \frac{2Wa_n}{K_g \rho_o V_e m S}$$

where

U_{de} derived gust velocity, ft/sec

W airplane weight, lb

a_n normal acceleration, g units (corresponds to Δn used in ref. 7)

K_g gust factor

ρ_o air density at sea level, slugs/cu ft

V_e equivalent airspeed, ft/sec

m lift-curve slope per radian

S wing area, sq ft

The gust factor K_g is a function of the mass ratio μ_g of the airplane and therefore varies with altitude and lift-curve slope. The values of K_g were therefore computed for the midpoint of each 5,000-foot-altitude increment for five values of the lift-curve slope between $M = 0$ and $M = 0.7$. These K_g values varied from 0.737 for $M = 0.65$ at 2,500 feet to 0.823 for $M = 0.15$ at 22,500 feet for operator A, and from 0.726 for $M = 0.65$ at 2,500 feet to 0.817 for $M = 0.15$ at 22,500 feet for operator B. An average operating weight of 101,350 pounds for operator A, 92,000 pounds for operator B, and 95,000 pounds for operator C was used in calculating the gust velocities. These values for the average operating weights were obtained from the airlines. The variation of the lift-curve slope with Mach number was obtained from the manufacturer and is given in figure 6.

V-G Records

The values read from each V-G record were the maximum positive and negative accelerations $a_{n,max}$, the airspeeds at which the maximum accelerations occurred, and the maximum indicated airspeed V_{max}. Accelerations which occurred at low speeds (below 130) knots were not read in order to exclude the effects of maneuvers during take-off and approach and impact shocks during landing.

Maximum derived gust velocities were computed for each record by use of the revised gust-load formula. (See ref. 7.) The values of the gust factor K_g used for evaluating the gust velocities for the V-G data were based on the average operating altitude as determined from VGH data and on the average operating weights as furnished by the operator.

Reliability of Results

The three possible sources of error in the data arise from instrument, installation, and reading errors. The errors inherent in the instruments and those due to installation are discussed in references 3 and 4. Record reading errors are discussed in references 5 and 8. The most pertinent considerations to the reliability of the data presented are given in the following paragraphs.

The VGH installations met the installation requirements given in reference 3; therefore, the installation errors for the present data are thought to be negligible. The estimated maximum instrument errors in the VGH data for each of the measured quantities are:

Acceleration, g units	±0.05
Indicated airspeed, knots:	
At 100 knots	±5
At 300 knots	±3

Pressure altitude, ft:

At 2,000 ft	±150
At 20,000 ft	±300

From laboratory calibrations of the V-G recorder (ref. 4) the instrument errors are less than ±0.1g for acceleration and about 1 percent of the full range of airspeed covered by the recorder.

Random errors that may have occurred in reading the V-G records are believed to have a negligible effect on the V-G data. Errors in reading the VGH records, although estimated to be small (of the order of 0.05g) can affect the estimated number of accelerations exceeding given values. Experimental checks have indicated that for individual records the counts above 0.3g are only reliable to about ±30 percent. Inasmuch as the reading errors tend to balance out as the sample size increases, the values for the cumulative frequency per mile for the overall distribution of maneuver and gust accelerations and gust velocity are estimated to be accurate within ±20 percent. The accuracy of the distribution by flight condition and altitude bracket, however, is somewhat less inasmuch as the individual data samples are smaller.

In regard to the statistical reliability (that is, applicability to extended periods of operations) of the results, it should be noted that the data samples are limited in two primary aspects. First, the VGH data sample from each airline is smaller than the 1,000 hours usually considered as being adequate. Secondly, none of the samples cover a full year's operation and thus may not be completely representative of overall operations. The data sample for airline C is especially limited in both aspects; thus, the results for this sample should be used with reservation. The results for airlines A and B are, in spite of the sample limitations, believed to be fairly representative of these two operations.

RESULTS AND DISCUSSION

Description of Operations

As shown in figure 3, the airplanes were operated by the three airlines on routes which gave a wide geographical coverage of the United States. As an illustration of these operations, figure 7 gives altitude and airspeed profiles for a typical operational flight. The distribution of flight times for the operational flights is shown in figure 8 for each of the three operations.

Table II summarizes the average flight times and the average flight miles associated with the climb, cruise, and descent flight conditions and for the overall flight. As indicated in the table, the average flight lengths were approximately 550 miles and the average flight times were about 1.7 hours.

Table III gives a breakdown of the total flight time into the percentage of time flown within each 5,000-foot-altitude bracket and in the climb, cruise, and descent flight conditions. Although the airplanes were operated at altitudes up to 25,000 feet, the average cruise altitudes ranged from 17,317 feet for airline A to 17,133 feet for airline C. Approximately 10 percent of the flight time was spent in the climb, 65 percent in cruise, and 25 percent in descent.

Accelerations

Operational maneuvers.- The frequency distributions of the operational maneuver accelerations are summarized in table IV by flight condition and for the total data sample for airlines A and B. The maneuver accelerations experienced in the different operations are compared in figure 9 in terms of the average frequency of occurrence per mile of flight. For comparison, the limits of the maneuver distributions given in reference 1 for several four-engine piston airplanes are also given in the figure. The results show that the operational maneuvers experienced in operations A and B are similar as regards magnitude and frequency of occurrence. Also, the maneuver experiences for the operations are in fair agreement with the results for past piston-engine operation.

Examination of table IV shows that, for each operation, most of the operational maneuvers ($> \pm 0.1g$) occurred during the descent and the least number during climb. The maneuver frequency distributions from table IV are plotted in figure 10 in terms of the average frequency of occurrence per mile of flight for each flight condition. The figure shows that, in general, the frequency per mile is higher for the climb and descent conditions than for the cruise condition. This result is due to altitude and heading changes being required more frequently during the climb and descent than during cruise.

Check-flight maneuvers.- The time spent in check flights was about 3 percent of the total flight time for airline A and about two percent for airline B. These percentages for the time spent in check flights are in good agreement with the results given in reference 1 for a number of piston-engine airplanes and in reference 2 for a turbine-powered airplane.

The accelerations experienced during the check flights are shown in figure 11 in terms of the average frequency of occurrence of accelerations greater than given positive or negative values. These results are based on the total flight miles (operational and check flights) for each data sample. For comparison, the range of corresponding results for four-engine piston airplanes (ref. 1) are indicated in the figure.

The results in figure 11 show that positive accelerations of given values were experienced with about the same frequency in the two operations. For both airlines the positive accelerations are within the limits of the piston-engine results. The negative accelerations for airline A appear to have occurred more frequently and to have reached larger values than those experienced by airline B and lie near the upper limit for the piston-engine airplanes. The difference between the negative accelerations for airlines A and B may be due to differences in check-flight procedures for the two airlines or to sampling errors associated with the relatively small data samples.

Gust accelerations.- The frequency distributions of the gust accelerations are given in table V by flight condition and for the total VGH data sample from each airline. For each operation, the table shows that the largest number of accelerations was experienced during descent and the least number during climb. In terms of the average frequency of occurrence per mile of flight, figure 12 shows that gust accelerations were experienced roughly five times more frequently during climb and descent than during cruise. This result is primarily a reflection of the time spent in climbing and descending through the lower altitudes where the turbulence is more frequent than at the higher altitudes as will be discussed in a later section.

The average frequency of occurrence of gust accelerations during operations in each 5,000-foot-altitude interval is given in figure 13. In general, the gust-acceleration frequencies show a decrease with increasing altitude. This result is also primarily due to the increased turbulence levels at the lower altitudes.

The average gust acceleration frequencies based on the total VGH data sample for each operation are shown in figure 14. For comparison, the limits of corresponding results for four-engine piston airplanes (ref. 1) are also shown on the figure. These results show that slightly larger accelerations were experienced by airline A than by airlines B or C. From the overall viewpoint the present results show little difference in the gust acceleration experience for the three operations at the lower acceleration values ($a_n < 0.6g$). Although differences are evident in the frequency of occurrence of the larger accelerations, it is thought that these differences may be due to sampling variability. The gust acceleration histories for the present airplane type fall in the upper half of the range of the acceleration histories for the piston-engine airplanes.

The gust acceleration data from the V-G and VGH data for airline A are plotted in figure 15 in terms of the cumulative frequency of occurrence of acceleration per mile of flight. As noted in reference 8 the synthesis of V-G and VGH data provides a means of estimating the overall acceleration history for an operation. Figure 15 shows that the V-G and VGH data are from, the overall viewpoint, in relatively good agreement at the higher acceleration values. (The departure of the V-G data from the VGH data at lower acceleration levels is normal and is due to the fact that only maximum accelerations, rather than complete frequency counts, are obtained from the V-G records.) Although the results from the V-G data tend to substantiate the high acceleration values from the VGH data, they do not extend the VGH results nor provide a good basis for extrapolation to higher accelerations. In this case, the V-G data sample (1,711 hours) appears to be too small to add appreciably to the VGH data.

Oscillatory accelerations.- In addition to maneuver and gust accelerations, an oscillatory type of acceleration was frequently experienced in flight as was previously mentioned. This acceleration, which is denoted oscillatory acceleration because of its behavior, was characterized by essentially symmetrical variations of the accelerometer trace about the normal 1 g level-flight position. In general, the accelerations had a period of about 6 seconds, were relatively constant in amplitude for a given occurrence, and varied in length from less than half a minute to more than an hour. (See fig. 5(a).) Occasionally, instances occurred in which the oscillations, lasting for perhaps half a minute, either converged or diverged and contained peak accelerations as high as ±0.8g. (See figs. 5(b) and 5(c).) Oscillatory accelerations of the type shown in figure 5 have been recorded on each of the six airplanes from which VGH records have been received.

The average number of oscillatory acceleration occurrences per hour of flight experienced during the period of operation analyzed is shown in figure 16 for one airplane operated by airline A and two by airline B. The results show that the number of occurrences or "patches" of oscillatory accelerations ranged from about 0.1 to 0.7 per hour of flight. There does not appear to be any significant difference among the frequency of occurrence of the oscillations on the three airplanes. Also, no particular trend is apparent in the number of occurrences with time.

Figure 17 shows that the maximum amplitudes of the oscillatory accelerations for the records evaluated ranged from about ±0.1g to ±0.5g. There does not appear to be any significant difference between the maximum amplitudes for the three airplanes nor any particular trend in the amplitudes with time. It should be mentioned that convergent or divergent oscillations (figs. 5(b) and 5(c)) on records which were not included in the evaluations have attained peak accelerations as high as ±0.8g.

The estimated cumulative frequency per mile of oscillatory accelerations for airlines A and B are compared in figure 18. For this comparison, the number of peak accelerations was estimated by multiplying the average number of peaks per minute by the total time that oscillations of a given magnitude were present. Although this procedure gives a satisfactory estimate of the frequency of the low (less than about 0.3g) amplitude accelerations, it does not give a good estimate of the higher accelerations. The results indicate that the frequency of occurrence and amplitude of the oscillatory accelerations experienced by the airplanes flown by the two operators were about equal.

The joint distribution of the indicated airspeeds and pressure altitudes at which the oscillatory accelerations occurred is given in table VI. The results in table VI show that most of the oscillations occurred at speeds above about 220 knots and at altitudes above 12,000 feet. The distribution of the occurrences with altitude was found to be about the same as the distribution of cruise flight time at the various altitudes. Likewise, the distribution of the occurrences with airspeed closely agrees with the distribution of cruise airspeeds. Further, the line shown in table VI corresponding to the average cruise Mach number of 0.54 fits the joint airspeed - altitude distribution very well. Inasmuch as about 94 percent of the oscillatory accelerations occurred during cruise, the results in table VI indicate that the accelerations are not associated with any particular airspeed-altitude combination but, rather, occur randomly during cruise flight.

Oscillations of the type shown in figure 5 and which have been discussed in the preceding paragraphs have not been present on VGH records collected after March 27, 1960, when the 225-knot speed placard was placed on the airplanes and the autopilots were disconnected. However, oscillations with somewhat different characteristics occasionally are present on the records obtained after the placard. As shown in figure 19(a), these oscillations have a period of about 6 seconds and are generally less than ±0.25g. These oscillations have been recorded on each of the six airplanes. They have occurred in climb, cruise, and descent and, in some instances, appear to be initiated by light turbulence.

Although the oscillations detected after March 27, 1960 are generally of low amplitude and occur infrequently, there are some indications that they may amplify the airplane's response to rough air. For example, figure 19(b) shows a section of a VGH record taken in moderate turbulence. Examination of the acceleration trace suggests that the 6-second-period oscillation constitutes a predominate part of the total response to the rough air. Thus these oscillations are of sufficient importance to warrant investigation into their underlying cause.

<u>Comparison of accelerations</u>. - The accelerations caused by operational maneuvers, check-flight maneuvers, gusts and oscillatory motions

are compared in figure 20 in terms of the cumulative frequency per mile. For this comparison, the positive and negative accelerations for the check-flight maneuvers (fig. 11) have been combined without regard to sign. For each airline, gust accelerations are on the order of 10 times as frequent as accelerations from the other sources and, therefore, are the predominant source of accelerations.

Turbulence

Amount of rough air.- The percent of the flight distance which was flown in rough air is given in figure 21 by 5,000-foot-altitude intervals. For comparison, the curve given in reference 9 for the variation of the amount of rough air with altitude is also shown in figure 21. The results for the present operations indicate that the percentage of time spent in rough air decreased from roughly 30 percent at low altitude (0 to 5,000 feet) to about 8 percent at 15,000 feet. Above this altitude, the results indicate a small increase in the amount of rough air. In comparison with the results from reference 9, the present results show a larger percent of rough air throughout the altitude range covered. The present results and those of reference 9 are in general agreement, however, in regard to the trend of the variation of turbulence with altitude.

Gust velocities.- The overall distribution of gust velocities evaluated from the VGH records are shown in figure 22 in terms of the cumulative frequency of occurrence per mile of flight for the three operations. Comparison of the present operations with corresponding results from four-engine piston airplane (ref. 1) indicates general agreement; however, results from airline A are slightly higher. Comparison of the results for the present three operations indicates that gusts of given values were encountered several times more frequently by airline A than by the other two airlines. Such differences in gust experience for a particular type of airplane in operation on several routes are not unusual, however, and are apparently due to differences in the actual amount and intensity of turbulence present over the routes and to differences in operational practices as regards turbulence avoidance.

Figure 23 shows the average number of gusts encountered per mile of flight within each 5,000-foot-altitude interval for airlines A and B. In general, the results for each airline indicate significant decreases in the gust frequency with increasing altitude and, thus, are in overall agreement with previous results. (See refs. 1 and 9, for example.) Some deviation from the general pattern of decreasing gust frequency with increasing altitude is however evident in the present results inasmuch as the gust frequency for the altitude interval of 20,000 to 25,000 feet is higher than for altitudes of 15,000 to 20,000 feet. Whether this indication is real or results from sampling variability is not known at present. Similar indications, however, have been noted in other analyses of airline data. (See ref. 1.)

The distribution of gust velocities from V-G data from airline A is shown in figure 24 together with the VGH gust velocity data for the airline from figure 22. The results in figure 24 show that the two sets of data are not in good agreement and that the V-G data indicate a lower gust frequency than the VGH data. This lack of agreement is thought to be due in part to the relatively small V-G data sample available (1,711 hours) as was discussed in a previous section.

Airspeeds.- The average indicated airspeeds for the climb, cruise, and descent flight conditions and for overall flight are summarized in table VII for each airline. These data were obtained from the 1-minute airspeed readings of the VGH records. The differences among the average speeds for the three airlines are generally less than about 5 knots and, thus, indicate rather consistent airspeed practices for the three operations. The average airspeeds were roughly 215 knots during climb, 265 knots during cruise, and 240 knots during descent.

The average indicated airspeeds in rough and smooth air for each flight condition are given in table VIII. For this evaluation, rough air was defined as those portions of flight during which accelerations larger than about ±0.1g were experienced. In general, the results in the table show little difference in the average airspeeds during flight in rough and smooth air for the cruise condition. For the climb and descent conditions, however, the results indicate lower speeds in rough air than in smooth air.

Table IX summarizes the average indicated airspeeds for flight in rough and smooth air by 5,000-foot-altitude intervals. For airlines A and C the average speeds in rough air are generally slightly lower than the speeds in smooth air, whereas the reverse is indicated for airline B. The reason for this difference is not known.

As mentioned previously the airspeeds shown in table IX for flight in rough air are based on the flight time during which accelerations larger than ±0.1g accelerations were experienced. Thus, it may appear that the airspeeds are unduly biased by relatively large amounts of light turbulence encountered and for which airspeed reductions were not necessary. Examination of the airspeed-acceleration data indicated, however, that the larger accelerations generally occurred at the rough airspeeds shown in table IX and that significant airspeed reductions were not usually accomplished prior to encountering heavy turbulence.

The airspeeds given in table IX for flight in rough and smooth air at the various altitude intervals are plotted in figure 25. The placard normal operating limit speed V_{NO} and the placard never-exceed speed V_{NE} are also shown in the figure. The results show that the average indicated operating speeds increase with altitude up to about 15,000 feet and decrease above this altitude. In general, the margins between the average speeds and the placard speeds decrease with increasing altitude.

Results pertaining to speeds in excess of the placard V_{NO} and V_{NE} speeds are summarized in table X. The table gives the percent of the total flight time flown at speeds in excess of V_{NO} and V_{NE} and the percent of the flight on which the placard speeds were exceeded in each flight condition. Results are given for airlines A and B separately and also for the combined data samples from the two airlines.

Comparison of the results in table X for the two airlines indicates that the operating practices as regards maximum speeds were similar for the two operations. In each case, approximately 1 percent of the flight time was at speeds in excess of V_{NO} (or M_{NO}) and about 0.006 percent of the time was in excess of V_{NE} (or M_{NE}). The results also indicate that the overspeeding occurred primarily in descent, where speeds above V_{NO} were recorded on about 25 percent of the flights. More detailed analysis of the data has shown that the overspeeds are not associated with any particular altitude but rather occur throughout the operating altitude range. The frequency of exceeding placard speeds is higher for the present airplane than for past piston-engine airplanes. However, the percentage of the overspeed is about the same as for several other types of turbine-powered transports.

Landing Accelerations and Vertical Velocity

Landing accelerations.- The probability distributions of the landing impact accelerations (initial positive value) evaluated from VGH records are given in figure 26 for the three airlines. A band representing the limits of the landing-impact probability distributions based on a total of 3,462 landings of four 4-engine piston airplanes is also included in the figure for purposes of comparison. The probability distributions for airlines A and B are similar and both indicate a lower probability of experiencing large impact acceleration than is shown by the results for airline C. The results for airline C may not be representative of extended operations, however, inasmuch as the data sample is small (71 landings) and cover initial operations of the airplane by the airline. In comparison with the results for piston engine airplanes, the present results indicate a higher probability of experiencing large landing-impact accelerations.

Vertical velocities.- The probability distributions of vertical velocity at landing (estimated from the impact acceleration data in figure 26 by the method of ref. 6) are given in figure 27. The vertical-velocity distributions for the three airlines have the same relative position as the acceleration distributions in figure 26. The present results indicate a somewhat higher probability of experiencing vertical velocities of given values than is shown by the results for the four-piston-engine airplane. It may be mentioned, however, that the vertical velocities for the Electra are lower than the velocities for several other types of turbine-powered transports.

CONCLUDING REMARKS

An analysis of V-G and VGH data collected on several Lockheed Electra airplanes during routine commercial airline operations has provided information on a number of aspects concerning the operational experiences of the airplane prior to the March 27, 1960 speed restrictions. The results indicate that the accelerations caused by gusts and maneuvers are comparable to corresponding results for past piston-engine transport airplanes. Accelerations due to oscillatory motions of the airplane (apparently caused by autopilot or control system) appear to occur about one-tenth as frequently as gust accelerations. For the period after March 27, 1960, oscillatory accelerations having a period of about 6 seconds occasionally occur and may amplify the response of the airplane during flight in rough air.

The airspeed operating practices in regard to rough air do not appear to be different from past piston-engine transports. Placard speeds were exceeded more frequently in the operation of the Electra airplane than in operations involving piston transports. The overspeeding, however, does not appear to be significantly more prevalent on the Electra than on several other types of turbine-powered transports.

The landing-impact accelerations appear to be somewhat higher, on the average, than the accelerations for past operations of piston-engine transports.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., February 1, 1961.

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2. Copp, Martin R., and Fetner, Mary W.: Analysis of Acceleration, Airspeed, and Gust-Velocity Data From a Four-Engine Turboprop Transport Operating Over the Eastern United Stated. NASA TN D-36, 1959.

3. Richardson, Norman R.: NACA VGH Recorder. NACA TN 2265, 1951.

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5. Coleman, Thomas L., and Copp, Martin R.: Maneuver Accelerations Experienced by Five Types of Commercial Transport Airplanes During Routine Operations. NACA TN 3086, 1954.

6. Dreher, Robert C., and Batterson, Sidney A.: Estimation of Statistics of Vertical Velocity From Landing Accelerations and Airplane Weight. NASA TM X-238, 1960.

7. Pratt, Kermit G., and Walker, Walter G.: A Revised Gust-Load Formula and a Re-evaluation of V-G Data Taken on Civil Transport Airplanes From 1933 to 1950. NACA Rep. 1206, 1954. (Supersedes NACA TN's 2964 by Kermit G. Pratt and 3041 by Walter G. Walker.)

8. Press, Harry, and McDougal, Robert L.: The Gust and Gust-Load Experience of a Twin-Engine Low-Altitude Transport Airplane in Operation on a Northern Transcontinental Route. NACA TN 2663, 1952.

9. Press, Harry, and Steiner, Roy: An Approach to the Problem of Estimating Severe and Repeated Gust Loads for Missile Operations. NACA TN 4332, 1958.

TABLE I.- SIZE OF VGH DATA SAMPLES

Data sample	Airline		
	A	B	C
Total flight hours available	1,164.0	893.0	191.8
Flight hours evaluated for:			
Gust accelerations	809.5	575.4	155.7
Operational maneuvers	809.5	575.4	0
Check-flight maneuvers	834.6	585.6	0
Oscillatory accelerations	474.6	798.4	0
Airspeed and altitude distributions	494.0	575.4	155.7
Placard speed exceedances	1,164.0	893.0	0
Landings evaluated for:			
Landing-impact accelerations	584	441	71

TABLE II.- AVERAGE DISTANCES, TIME, AND

CRUISE ALTITUDES FOR FLIGHTS

Airline	Climb		Cruise			Descent		Total	
	Distance, miles	Time, hrs	Distance, miles	Time, hrs	Altitude, ft	Distance, miles	Time, hrs	Distance, miles	Time, hrs
A	54	0.19	431	1.11	17,317	114	0.37	599	1.67
B	52	.19	379	.96	17,313	115	.36	546	1.51
C	54	.19	433	1.27	17,133	118	.39	605	1.85

TABLE III.- PERCENT OF TOTAL TIME BY ALTITUDE BRACKETS AND BY FLIGHT CONDITION

Altitude, ft	Percent of time for airline:		
	A	B	C
0 to 5,000	11.8	11.7	12.8
5,000 to 10,000	12.0	11.9	10.6
10,000 to 15,000	18.7	17.7	22.0
15,000 to 20,000	36.5	50.2	41.9
20,000 to 25,000	21.0	8.5	12.7
Climb	11.3	12.3	11.2
Cruise	66.5	63.7	65.9
Descent	22.2	24.0	22.9

TABLE IV.- FREQUENCY DISTRIBUTIONS OF OPERATIONAL

MANEUVER ACCELERATIONS

Acceleration, $\pm a_n$, g units	Frequency distribution for -							
	Climb		Cruise		Descent		Total	
	Airline		Airline		Airline		Airline	
	A	B	A	B	A	B	A	B
0.1 to 0.2	3,975	3,334	5,923	3,456	10,164	5,230	20,062	12,020
0.2 to 0.3	342	291	456	376	551	475	1,349	1,142
0.3 to 0.4	47	49	105	91	117	83	269	223
0.4 to 0.5	15	10	30	23	29	17	74	50
0.5 to 0.6	6	2	9	10	2		17	12
0.6 to 0.7	1		1	2			2	2
0.7 to 0.8					1			1
0.8 to 0.9			1		1			2
Total	4,386	3,686	6,525	3,958	10,865	5,805	21,776	13,449
Flight miles	2.1×10^4	2.0×10^4	21.4×10^4	14.4×10^4	5.7×10^4	4.4×10^4	2.9×10^5	2.1×10^5

TABLE V.- FREQUENCY DISTRIBUTION OF GUST ACCELERATION

BY FLIGHT CONDITION

Acceleration, $\pm a_n$, g units	Frequency distribution for -							
	Climb		Cruise		Descent		Total	
	Airline		Airline		Airline		Airline	
	A	B	A	B	A	B	A	B
0.2 to 0.3	1,585	680	3,552	1,988	5,463	2,570	10,600	5,238
0.3 to 0.4	314	185	687	312	1,049	537	2,050	1,034
0.4 to 0.5	96	47	198	103	247	149	541	299
0.5 to 0.6	27	15	59	27	81	48	167	90
0.6 to 0.7	6	7	17	4	19	19	42	30
0.7 to 0.8	4		12	3	8	6	24	9
0.8 to 0.9		2	8		1	1	9	3
0.9 to 1.0	2		1	1	1		4	1
1.0 to 1.1					1		1	
1.1 to 1.2			1		1		2	
1.2 to 1.3	1						1	
Total	2,035	936	4,535	2,438	6,871	3,330	13,441	6,704
Flight miles	2.1×10^4	2.0×10^4	21.4×10^4	14.4×10^4	5.7×10^4	4.4×10^4	2.9×10^5	2.1×10^5

TABLE VI.- JOINT AIRSPEED - ALTITUDE FREQUENCY DISTRIBUTION

FOR OSCILLATORY ACCELERATION OCCURRENCES

Indicated airspeed, knots	Altitude, ft												Number of cases
	0 to 12,000	12,000 to 13,000	13,000 to 14,000	14,000 to 15,000	15,000 to 16,000	16,000 to 17,000	17,000 to 18,000	18,000 to 19,000	19,000 to 20,000	20,000 to 21,000	21,000 to 22,000	22,000 to 25,000	
100 to 150	1	2											3
150 to 160			1										1
160 to 170	1												1
170 to 180		1											1
180 to 190	2			1							1		4
190 to 200						1				1			2
200 to 210													
210 to 220											2	1	3
220 to 230	1					1						2	4
230 to 240			2	1	1	1		4	5	6	3	12	35
240 to 250	1		1	1	2	1	1	15	30	13	9	4	78
250 to 260	1		3	5	1	14	14	8	29	14	4	4	97
260 to 270	1			8	12	13	6	13	12	1	2		68
270 to 280	3		2	5	7	12	12	4	6	2	2	1	56
280 to 290	3	1	1	4	5	18	1	1	1				35
290 to 300	3	1	1	2	6	5	1	2				1	22
300 to 310		1		2	2								5
310 to 320				1									1
320 to 330	5												5
Number of cases	22	6	11	30	36	66	35	47	83	37	23	25	421

M = 0.54

TABLE VII.- AVERAGE INDICATED AIRSPEED

BY FLIGHT CONDITION

Airline	Indicated airspeed, knots, for -			
	Climb	Cruise	Descent	Total
A	215	262	239	251
B	211	266	245	254
C	217	259	234	249

TABLE VIII.- AVERAGE INDICATED AIRSPEEDS IN ROUGH

AND SMOOTH AIR BY FLIGHT CONDITION

Airline	Air condition	Indicated airspeed, knots, for -			
		Climb	Cruise	Descent	Total
A	Rough	201	256	206	226
	Smooth	217	262	248	255
B	Rough	212	267	229	245
	Smooth	211	266	249	255
C	Rough	207	246	211	225
	Smooth	218	260	240	252

TABLE IX.- AVERAGE INDICATED AIRSPEED IN ROUGH

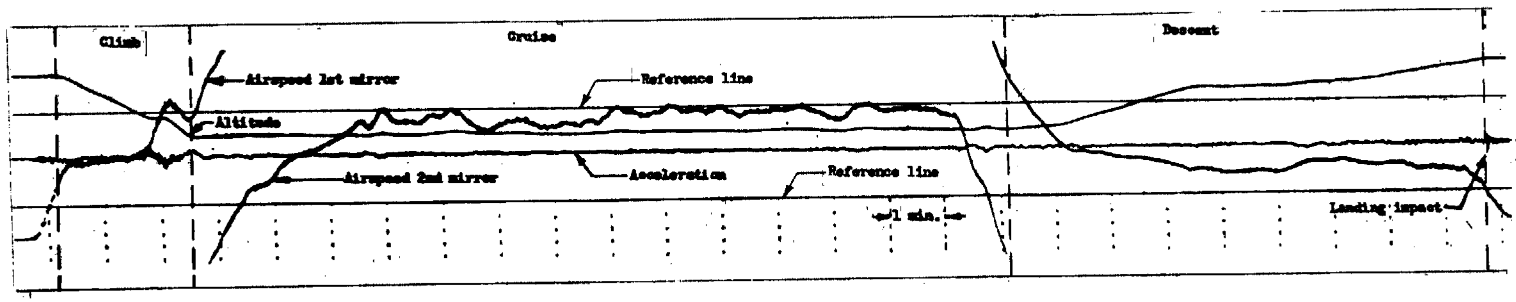
AND SMOOTH AIR BY ALTITUDE BRACKETS

Altitude, ft	Average indicated airspeed, knots, for -					
	Airline A		Airline B		Airline C	
	Rough	Smooth	Rough	Smooth	Rough	Smooth
0 to 5,000	178	203	198	190	198	198
5,000 to 10,000	252	257	263	253	239	255
10,000 to 15,000	271	276	274	266	266	268
15,000 to 20,000	260	262	266	266	241	257
20,000 to 25,000	235	241	254	254	244	243

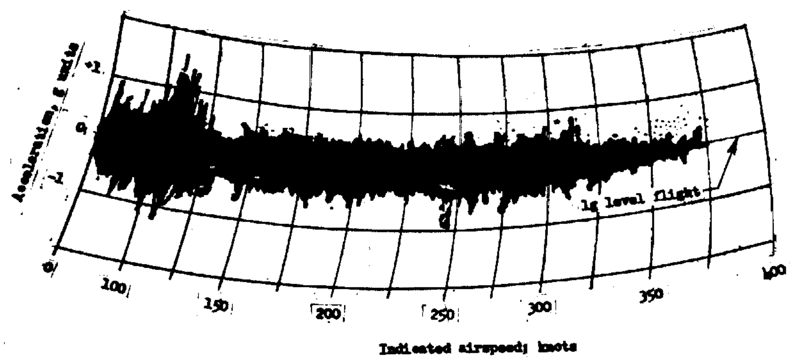
TABLE X.- PERCENT TIME V_{NO} AND V_{NE} EXCEEDED

IN CLIMB, CRUISE, AND DESCENT

	Airline A	Airline B	Airlines A and B
Number flights	747	582	1,329
Number flight hours	1,164	893	2,057
Percent total time flown above V_{NO} or M_{NO}	1.0	0.7	0.87
Percent of flights V_{NO} ($\text{or } M_{NO}$) exceeded:			
Overall	32.4	24.0	28.5
Climb	2.7	0.7	1.8
Cruise	5.6	4.5	5.1
Descent	27.5	23.4	25.7
Percent time flown above V_{NE} or M_{NE}	0.006	0.007	0.0064
Percent of flights V_{NE} ($\text{or } M_{NE}$) exceeded:			
Overall	1.10	1.20	1.13
Climb	0	0	0
Cruise	0.13	0.17	0.15
Descent	0.93	1.03	0.98



(a) VGH record.



(b) V-G record (200 hours).

Figure 1.- Illustrating V-G and VGH records.

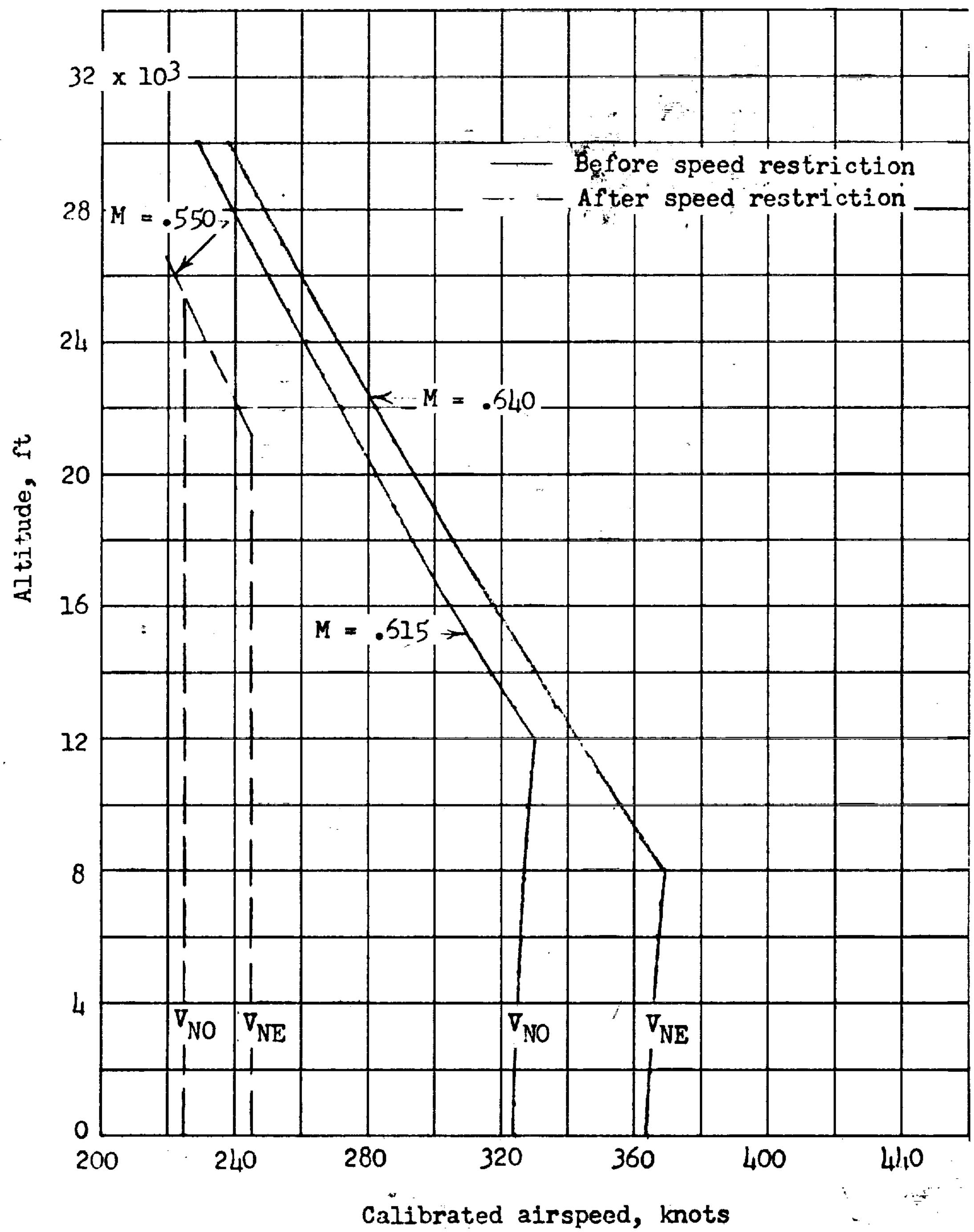
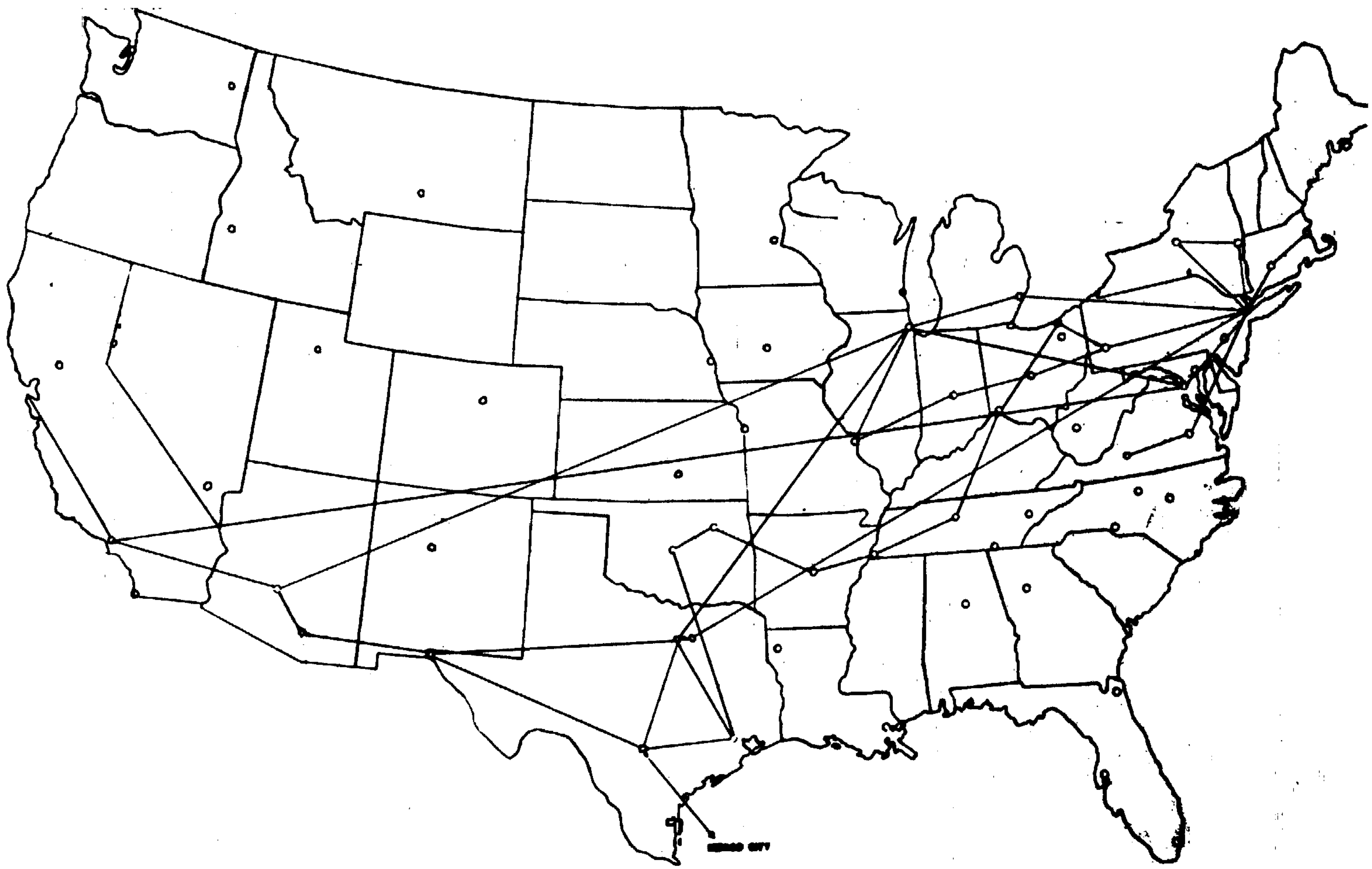
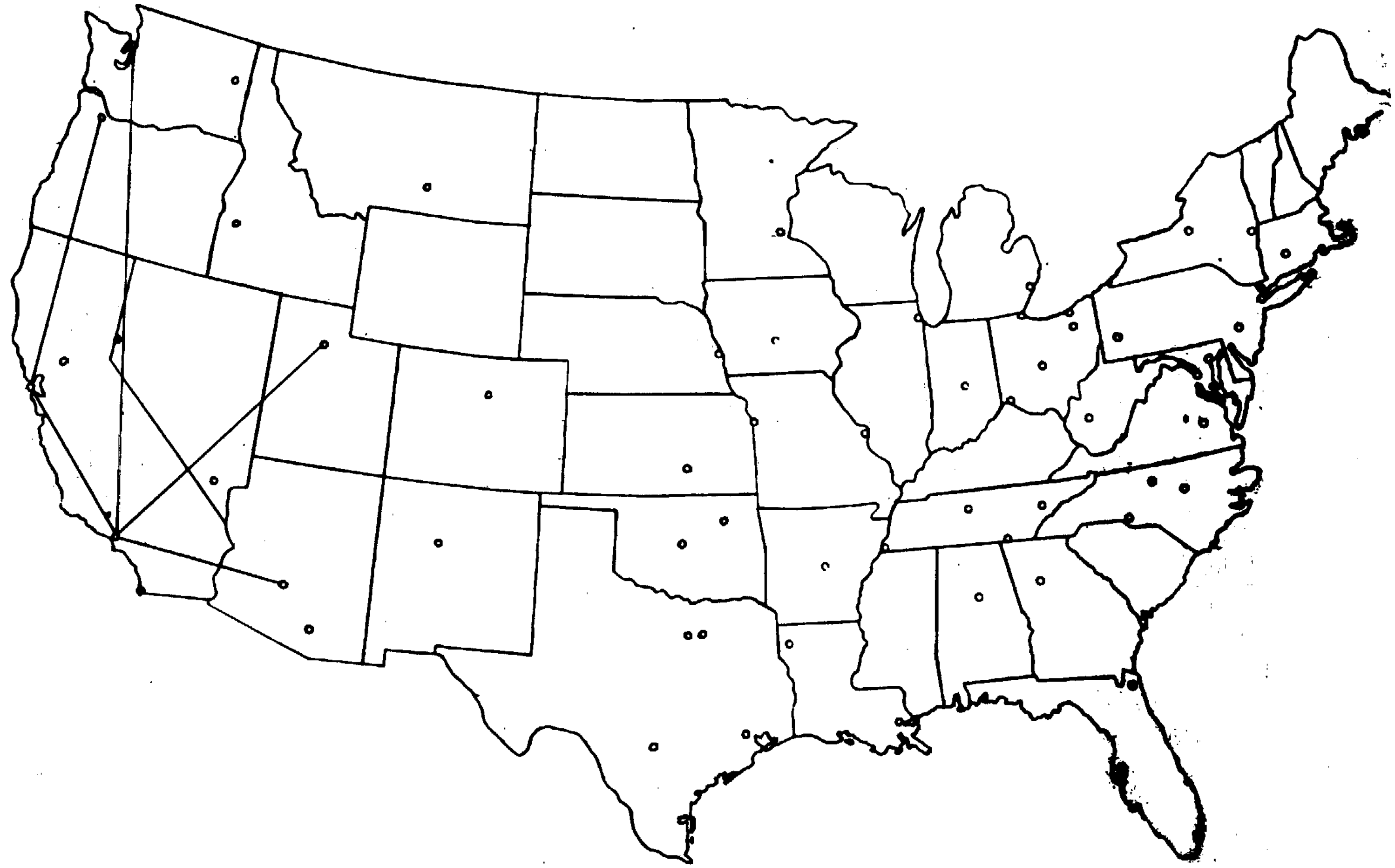


Figure 2.- Operational placard speeds before and after speed restriction.



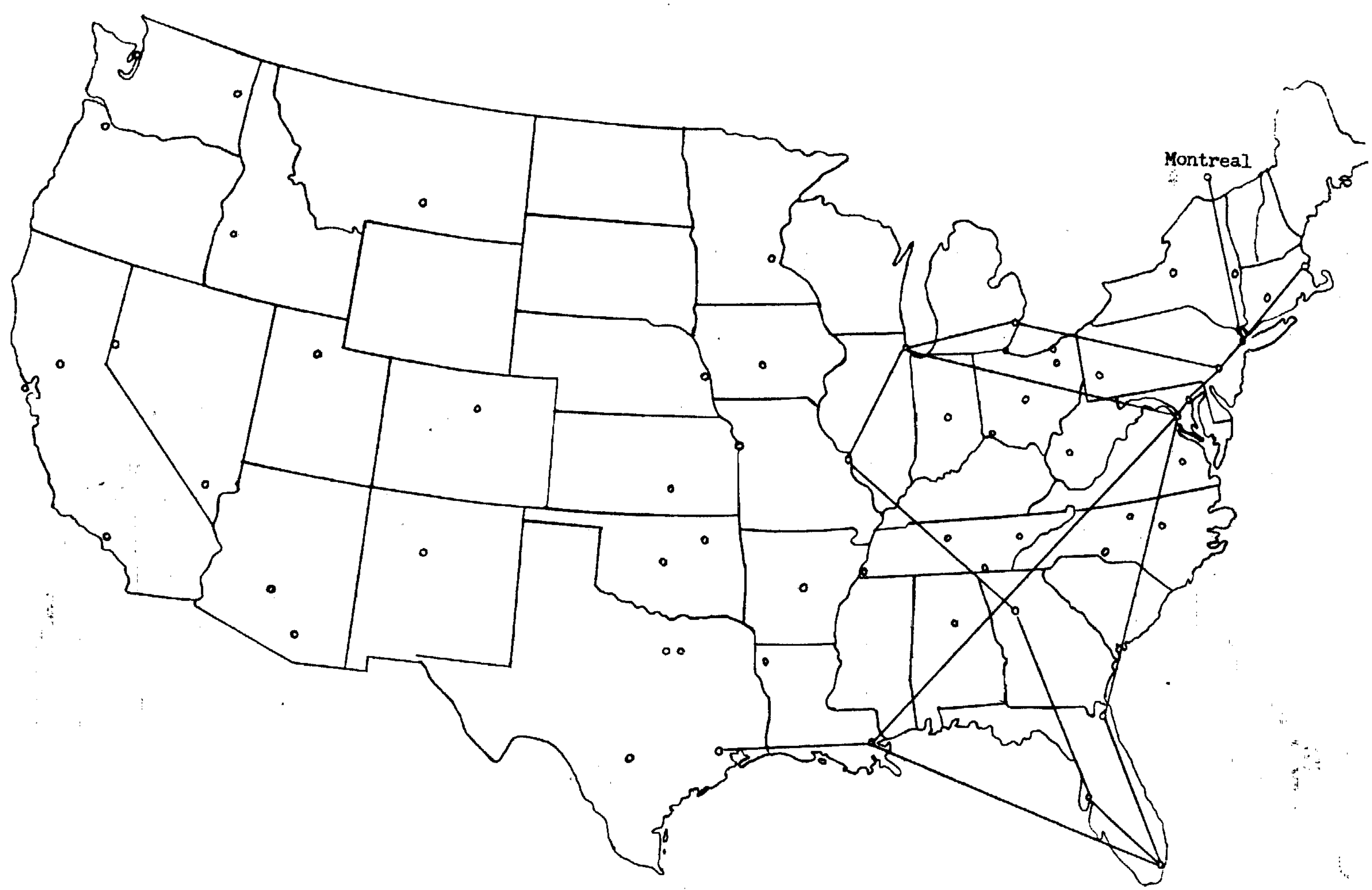
(a) Airline A.

Figure 3.- General routes covered by Electra VGH data.



(b) Airline B.

Figure 3.- Continued.



(c) Airline C.

Figure 3. - Concluded.

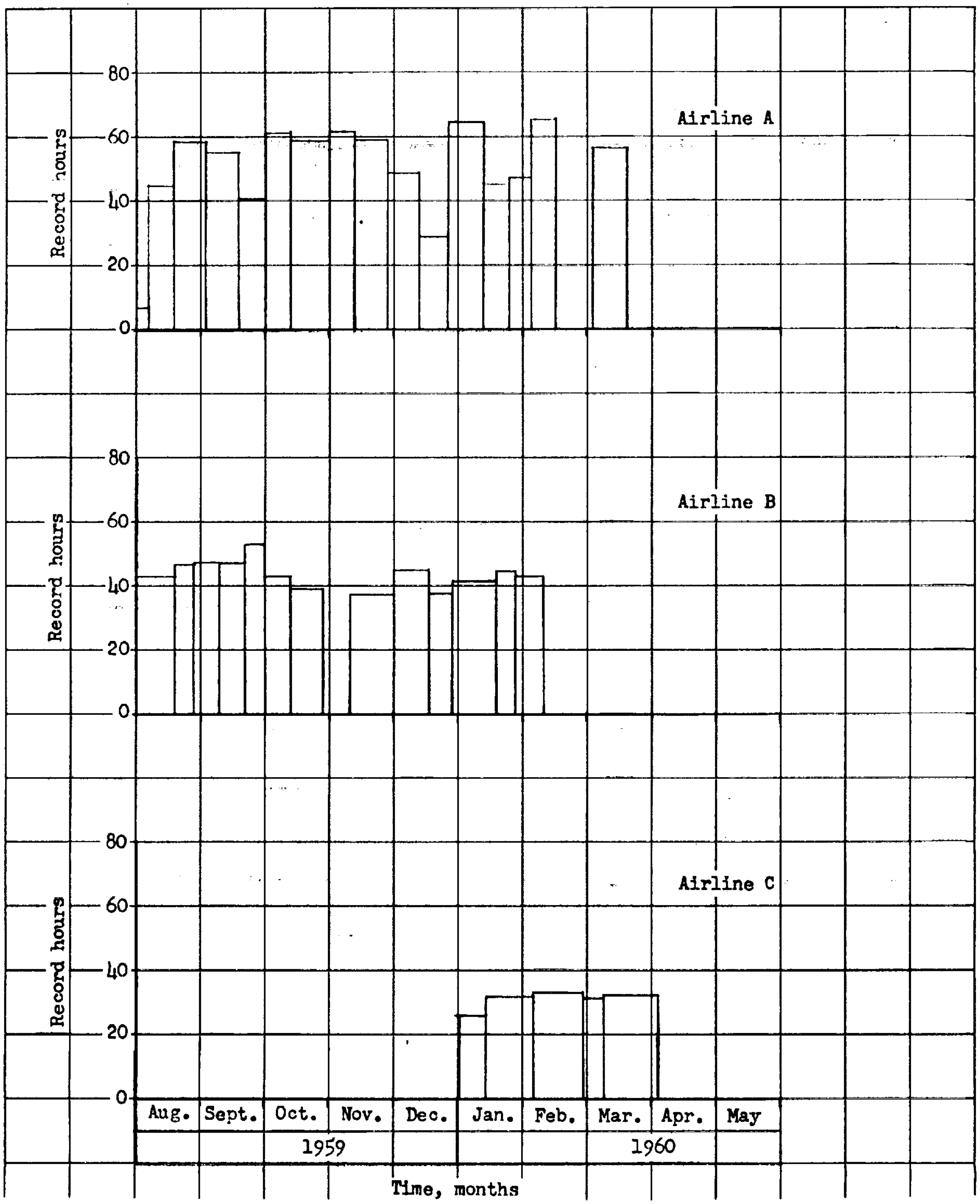
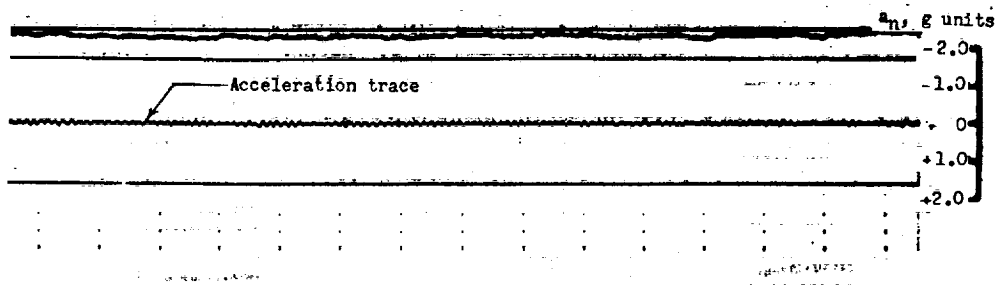
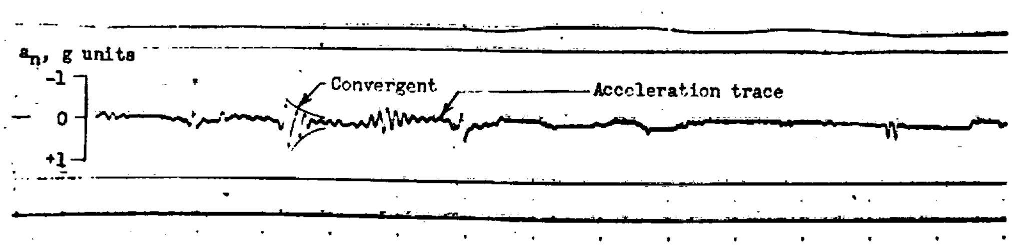


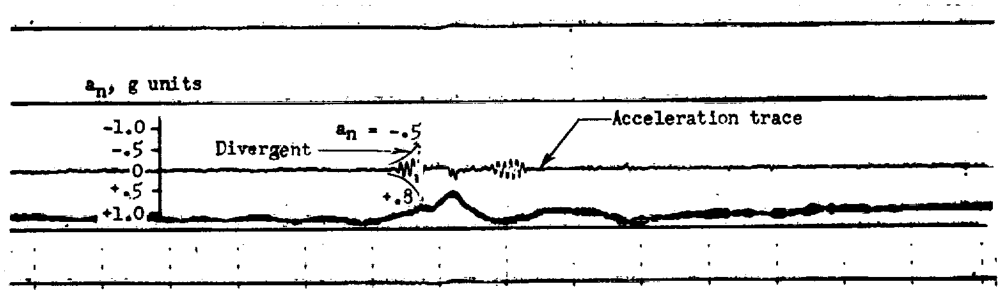
Figure 4.- Monthly distribution of VGH record hours for three airline operations.



(a) Constant-amplitude oscillations.



(b) Convergent oscillations.



(c) Divergent oscillations.

Figure 5.- Examples of oscillatory accelerations.

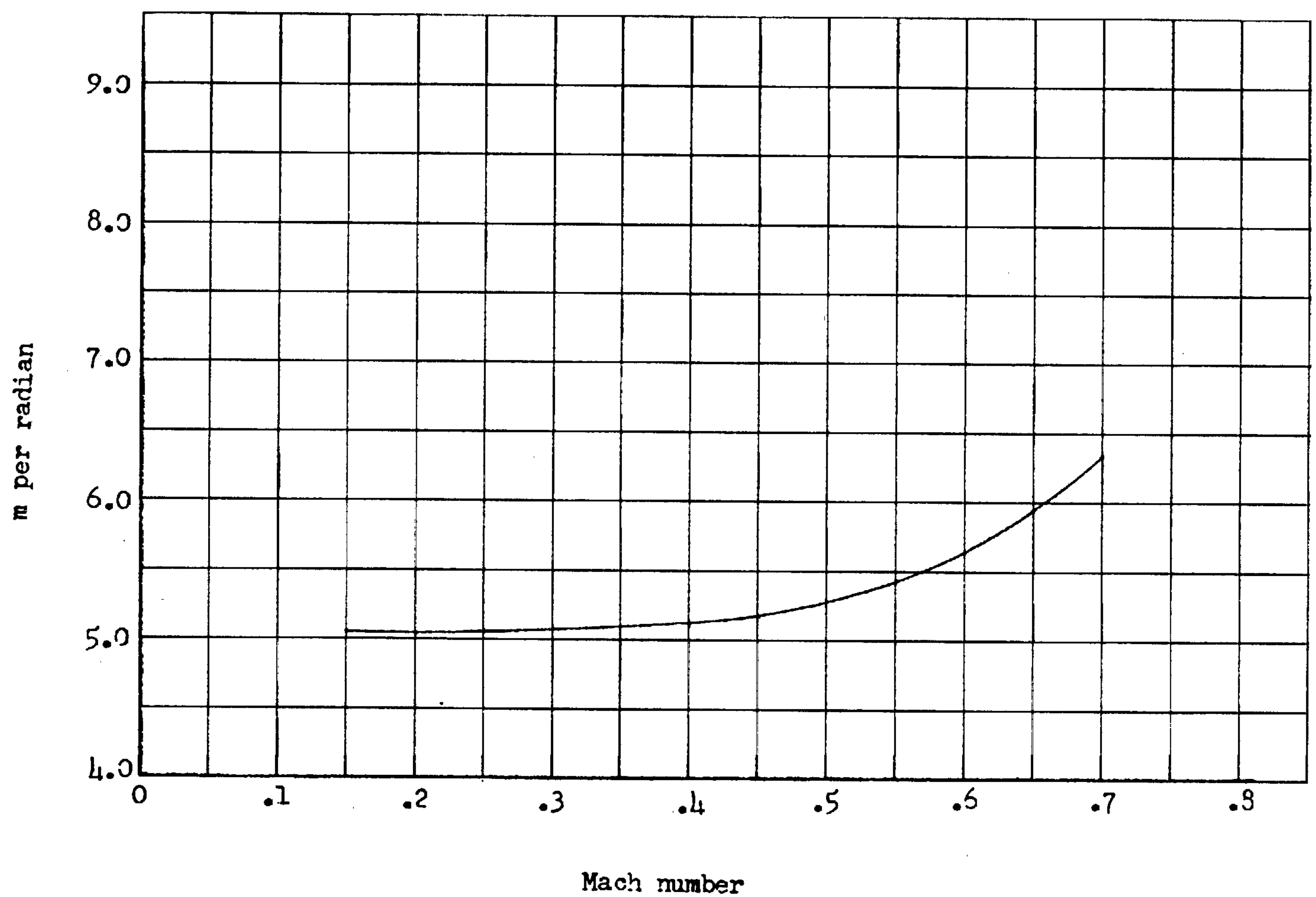


Figure 6.- Variation of lift-curve slope with Mach number. (Data obtained from manufacturer; airplane trimmed and clean, and power off.)

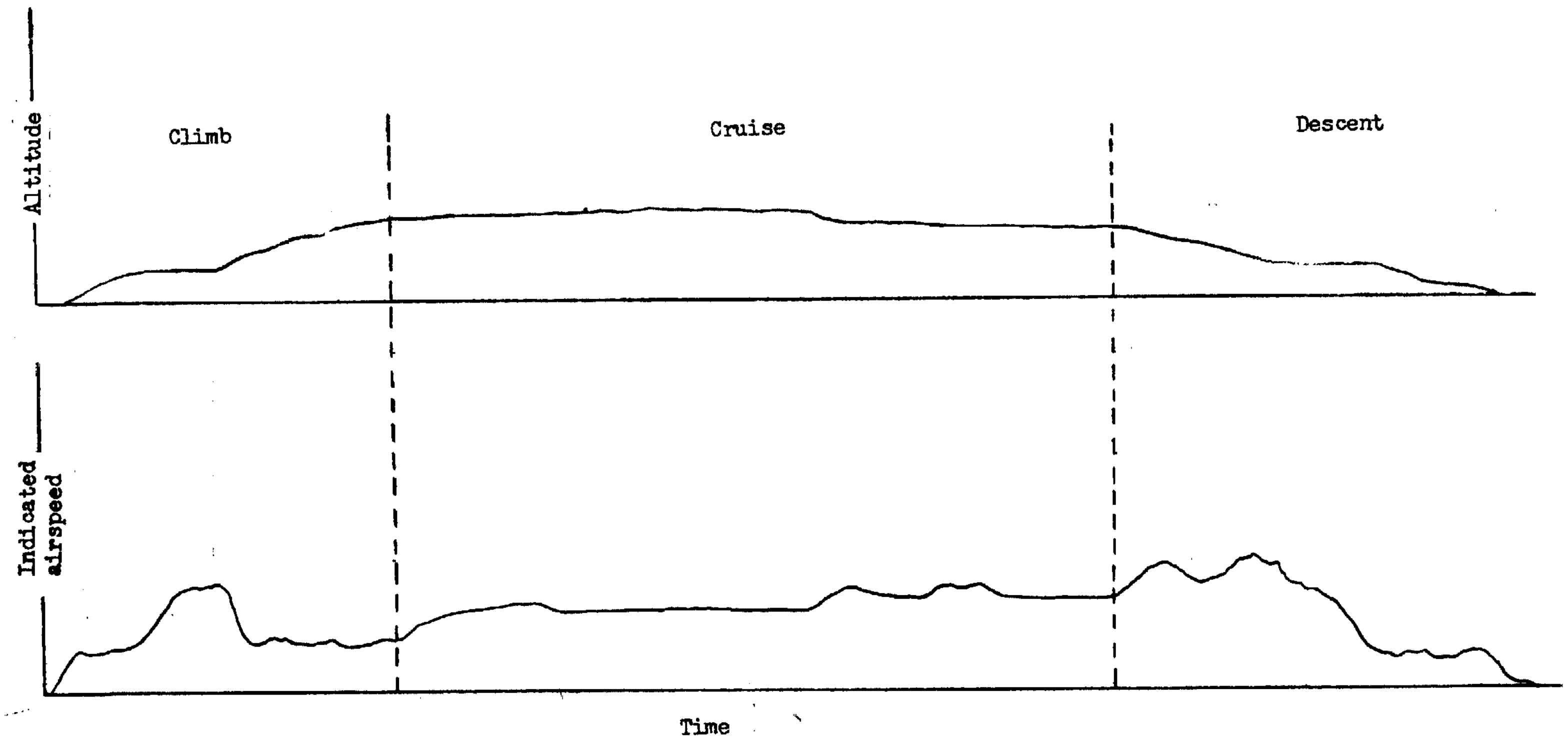


Figure 7.- Illustrative flight profile.

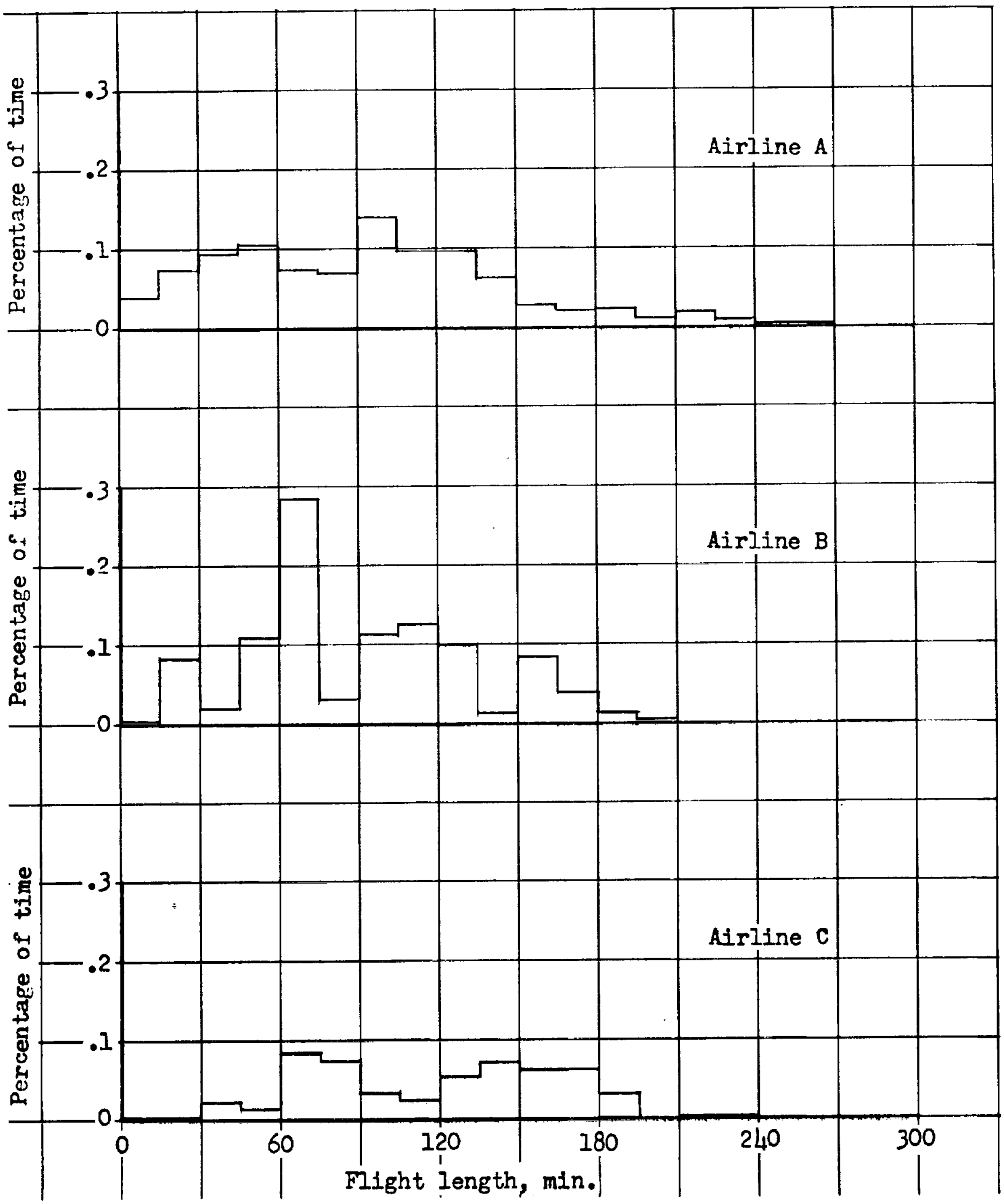


Figure 8.- Distribution of flight time for operational flights.

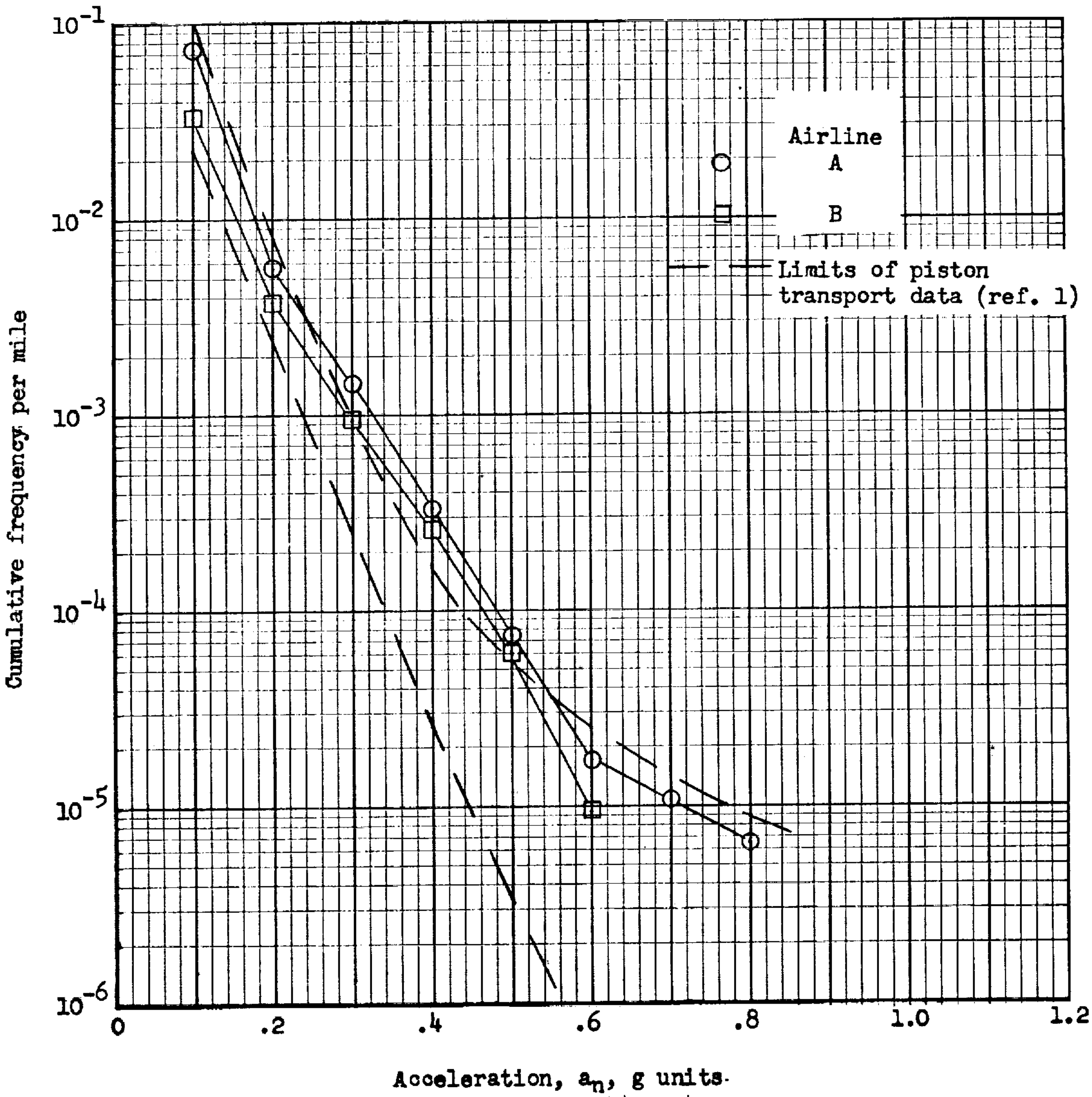
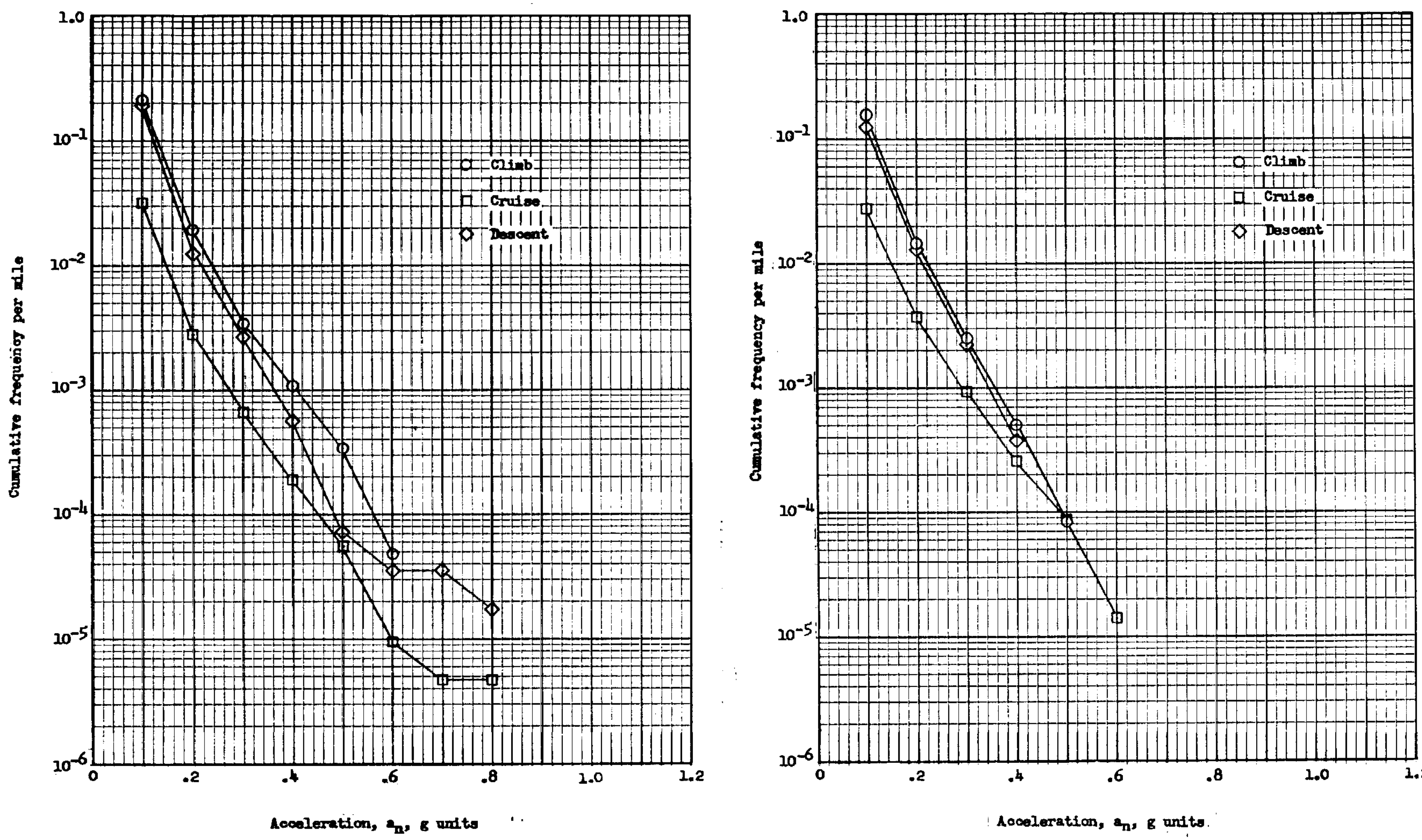


Figure 9.- Comparison of the overall operational maneuver accelerations encountered per mile of flight by two airlines.



(a) Airline A.

(b) Airline B.

Figure 10.- Operational maneuver accelerations encountered per mile of flight in climb, cruise, and descent.

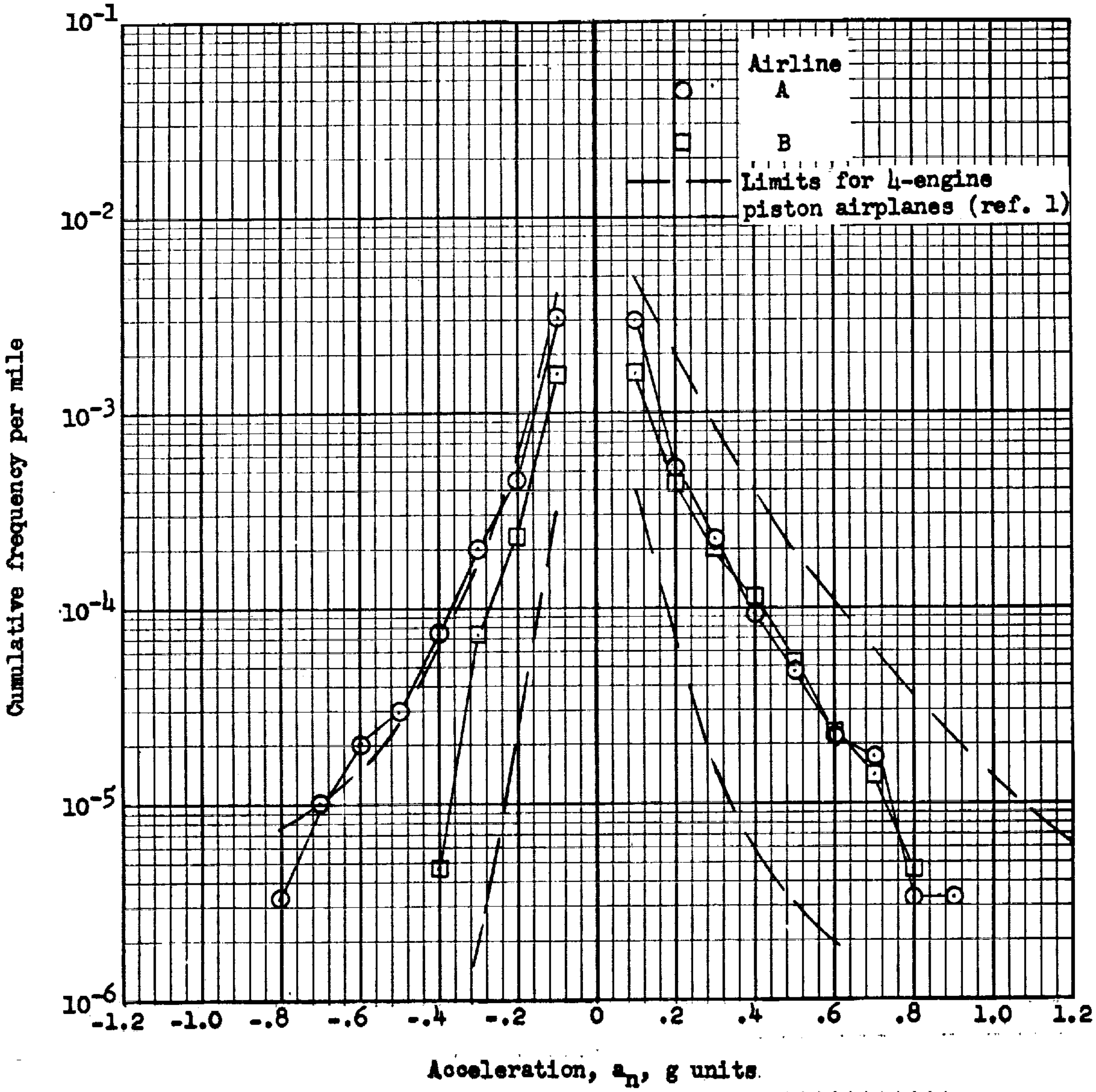
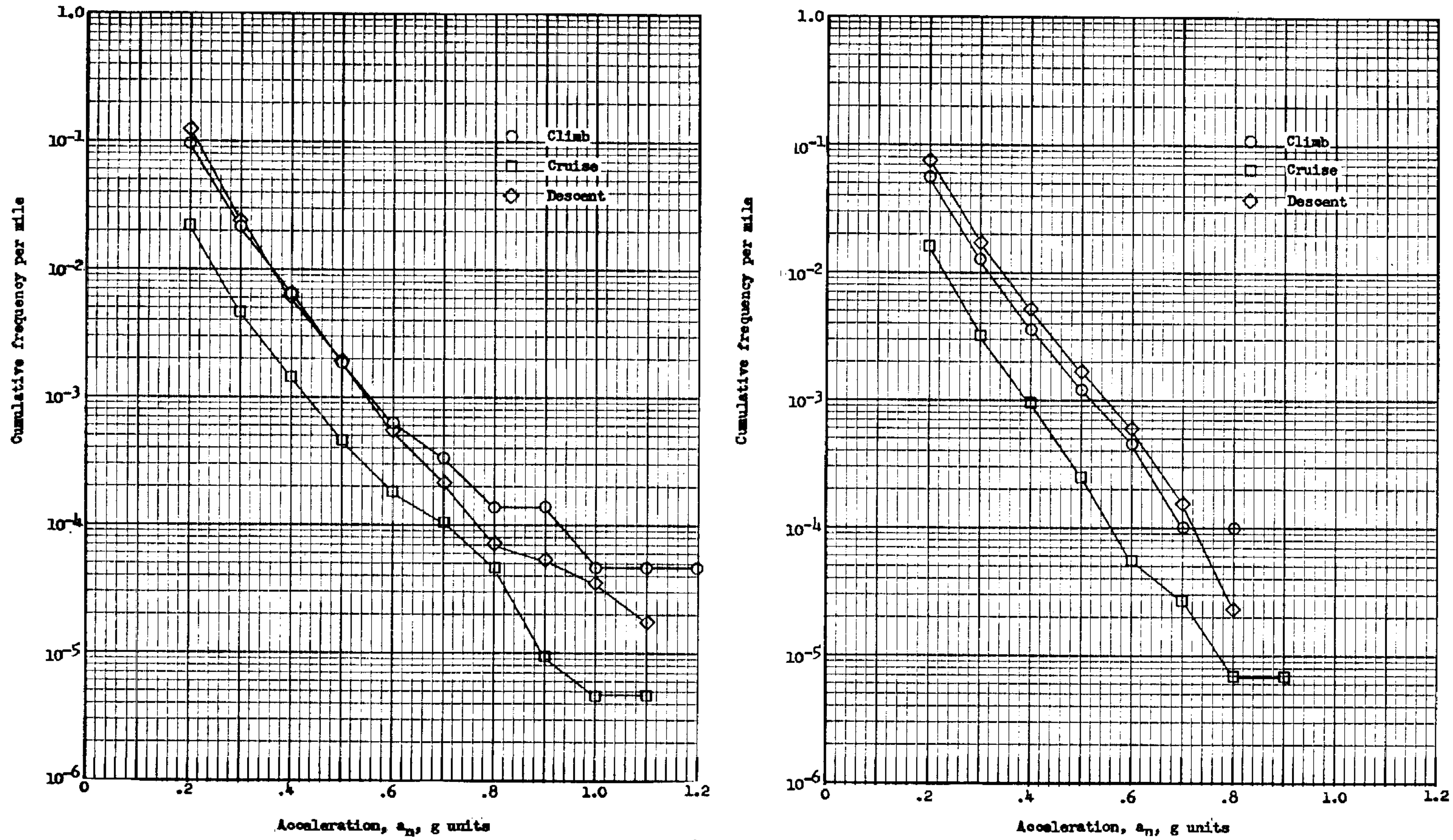


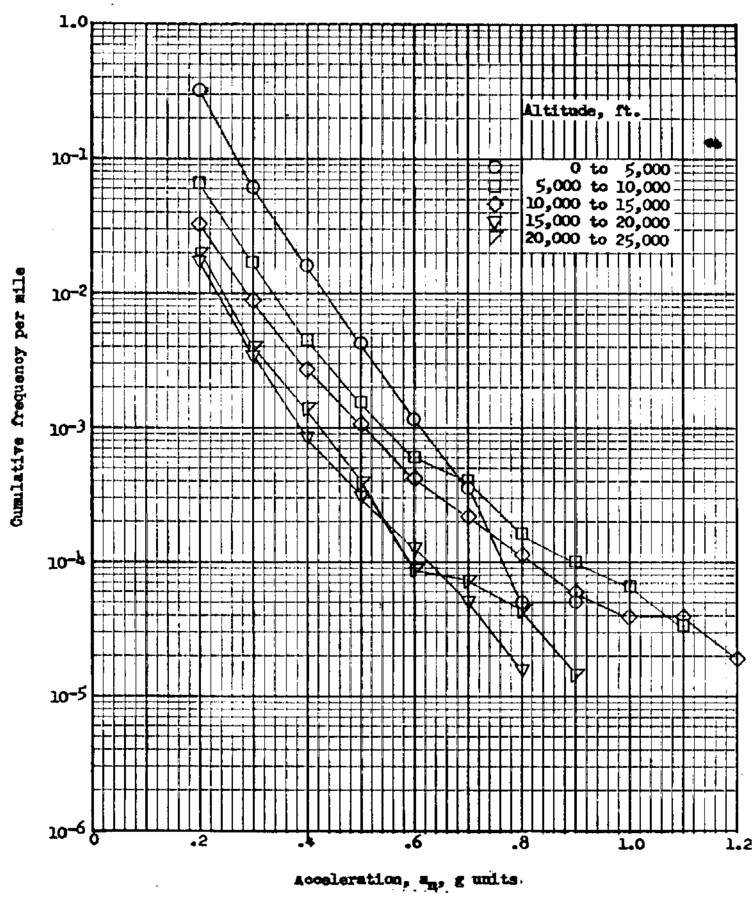
Figure 11. - Positive and negative maneuver accelerations experienced per mile of flight during check-flight operations.



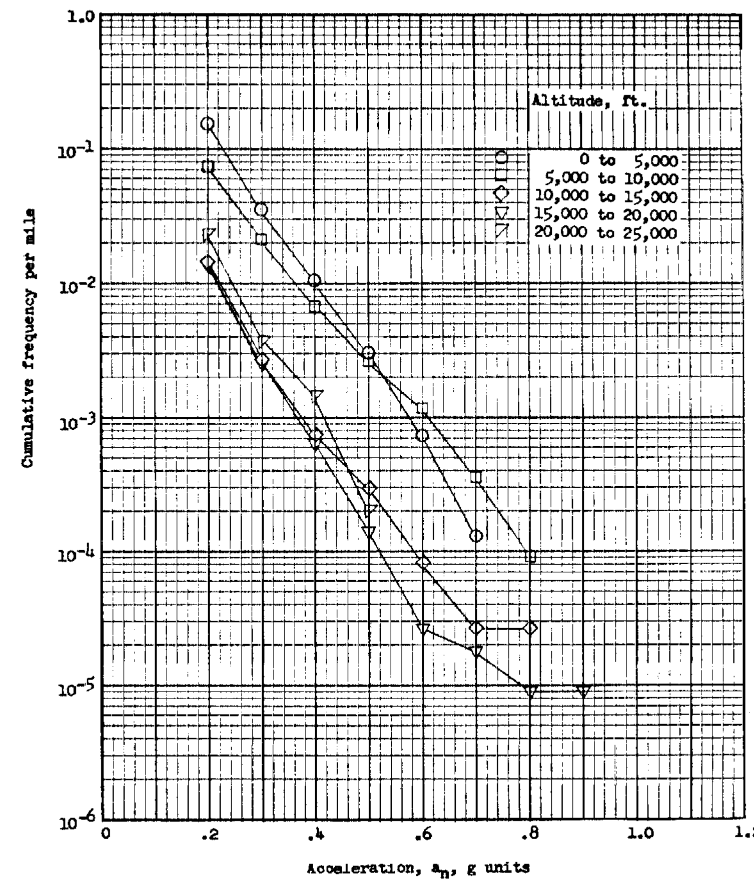
(a) Airline A.

(b) Airline B.

Figure 12.- Gust accelerations encountered per mile of flight in climb, cruise, and descent.



(a) Airline A.



(b) Airline B.

Figure 13.- Gust accelerations encountered per mile of flight by altitude brackets.

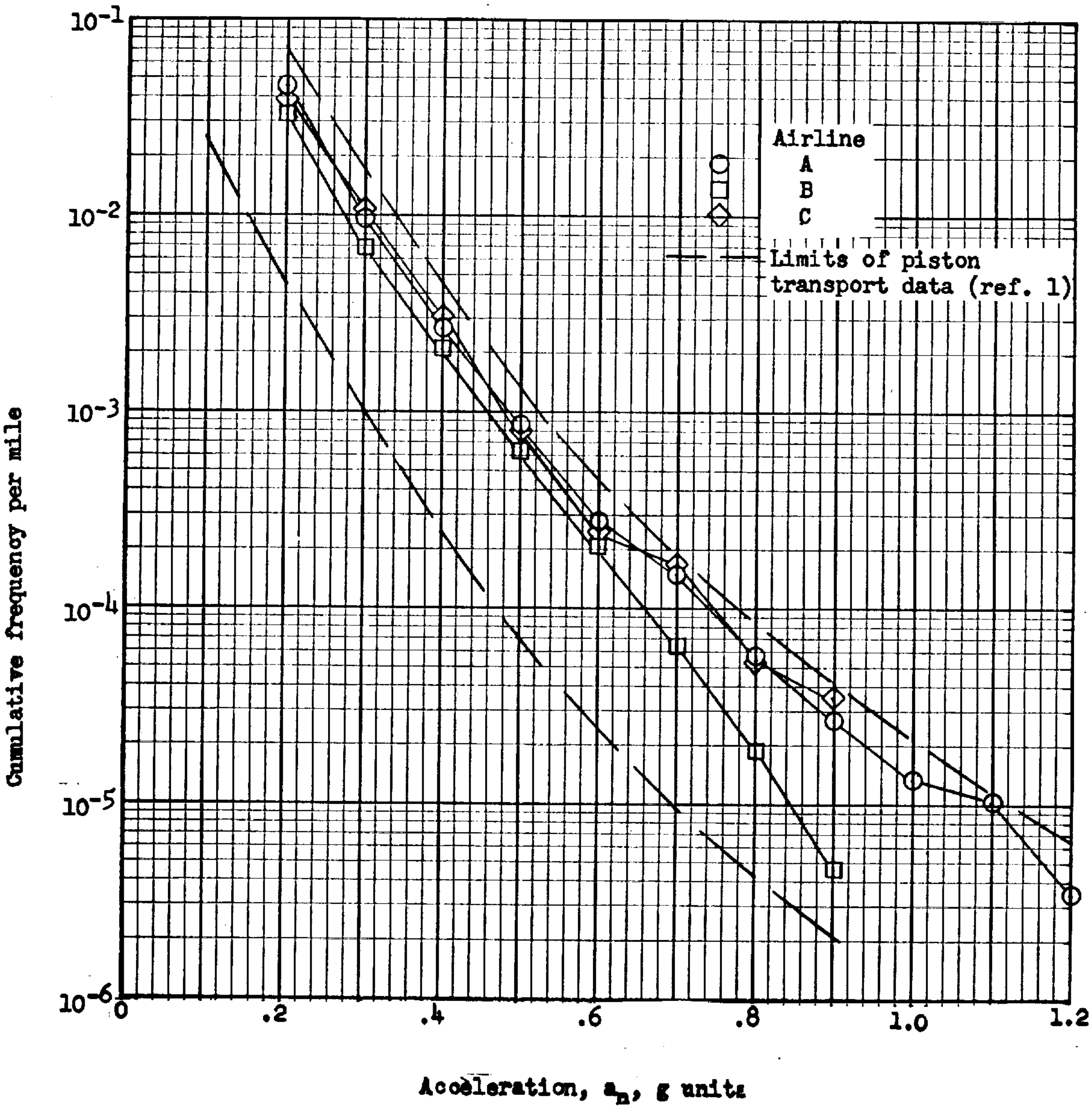


Figure 14.- Comparison of gust accelerations encountered per mile of flight by three operators.

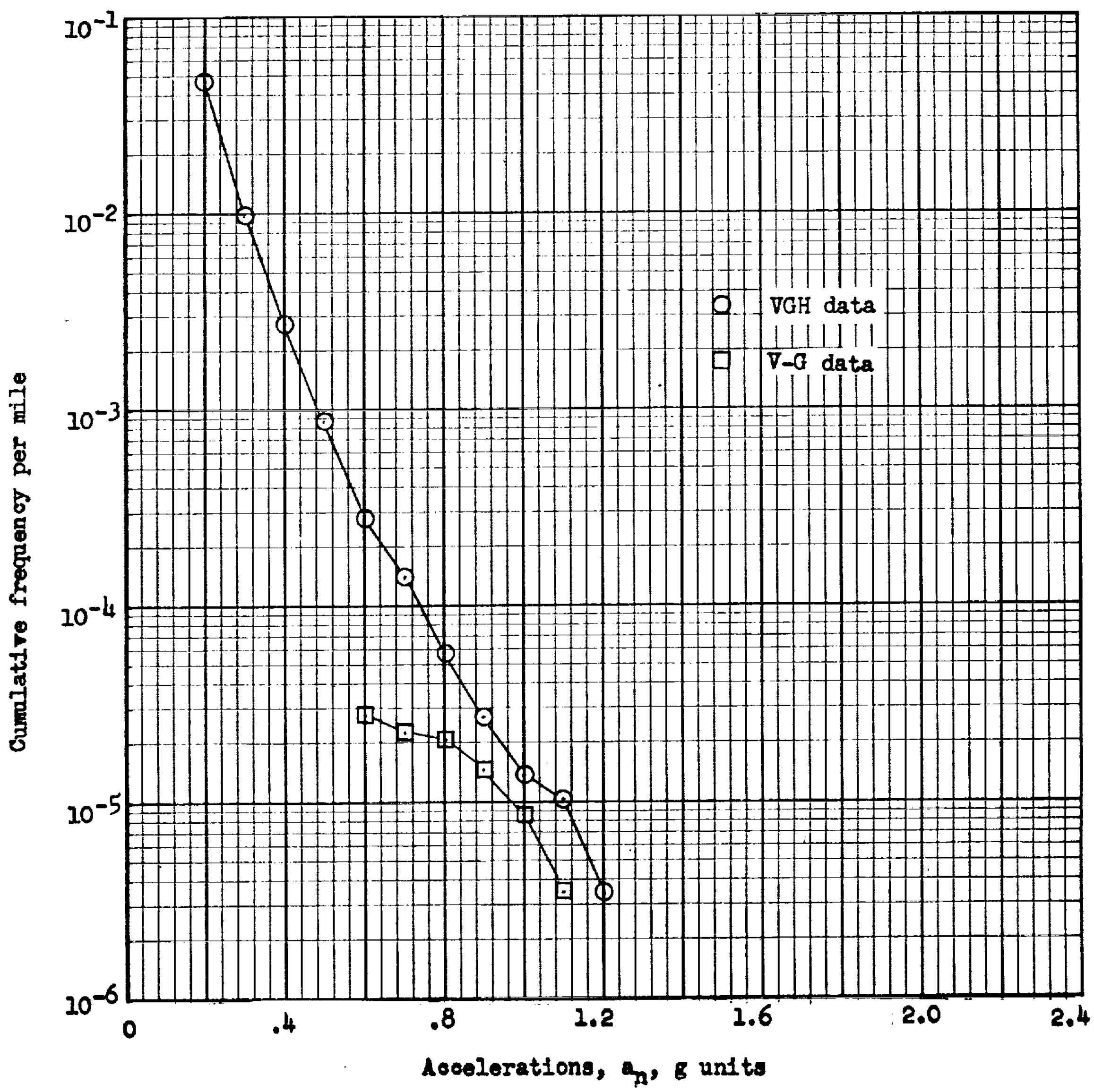


Figure 15.- Comparison of VGH and V-G gust accelerations for airline A.

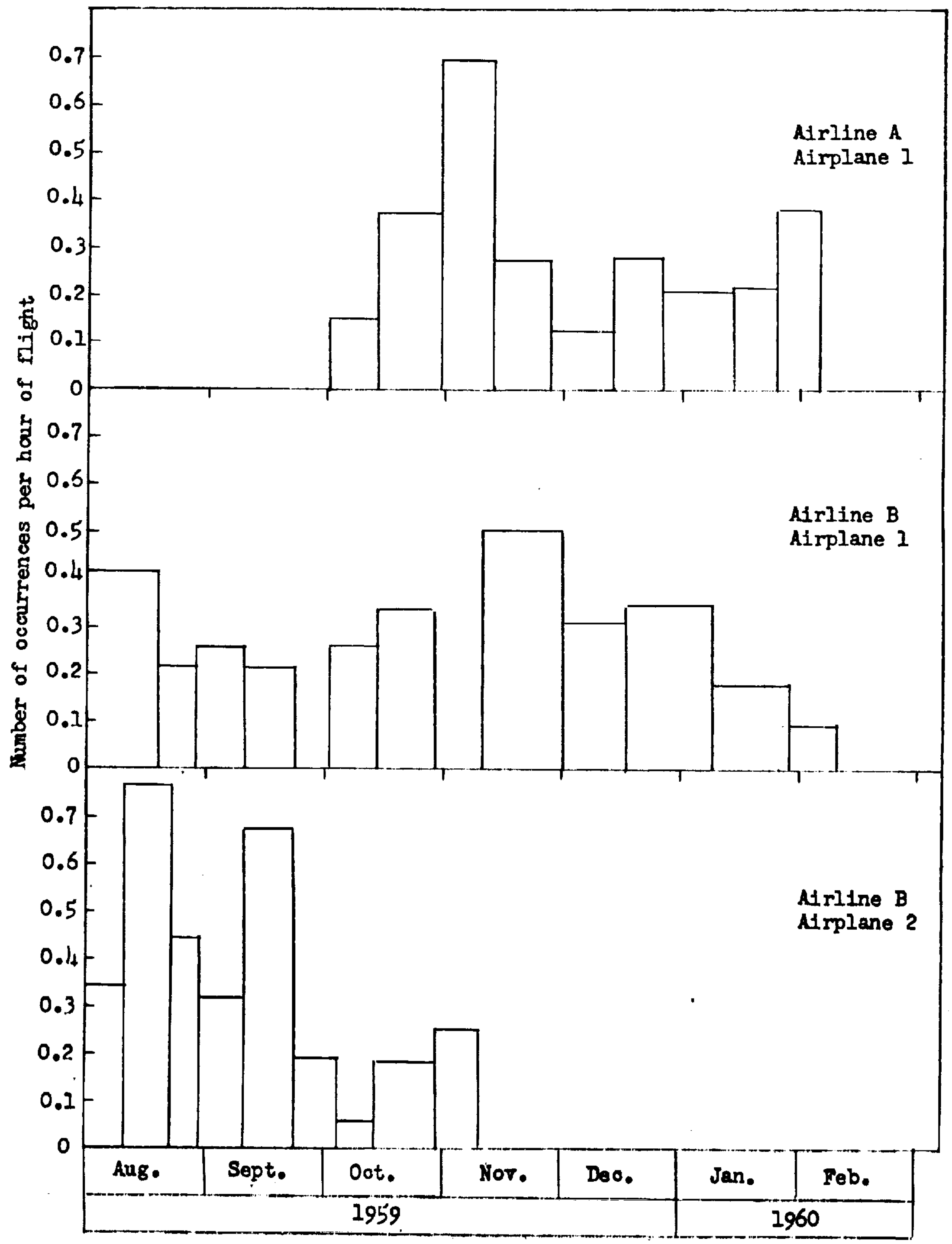


Figure 16.- Number of oscillatory acceleration occurrences per hour of flight for each record. (Each bar represents one VGH record.)

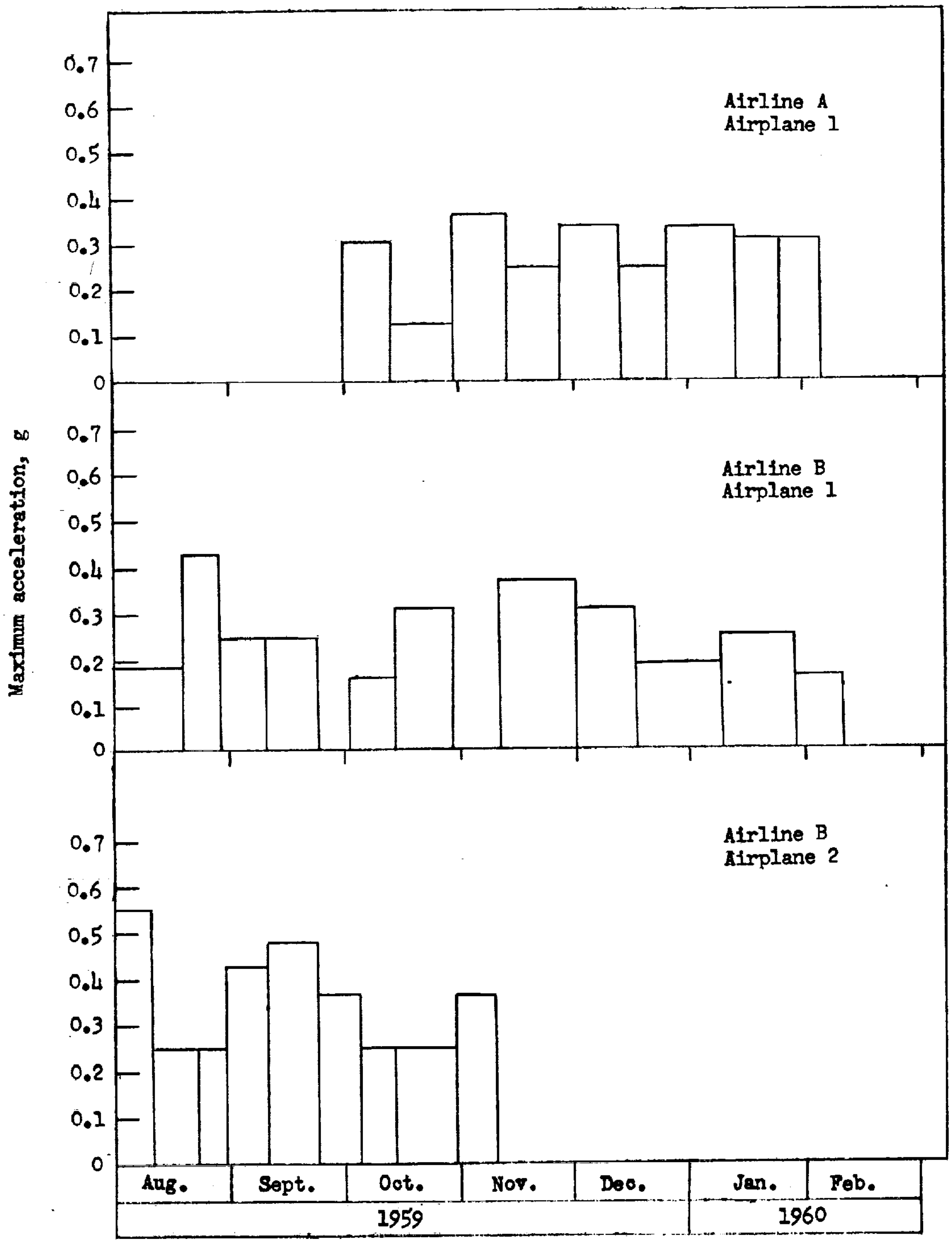


Figure 17.- Maximum oscillatory accelerations for each record. (Each bar represents one VGH record.)

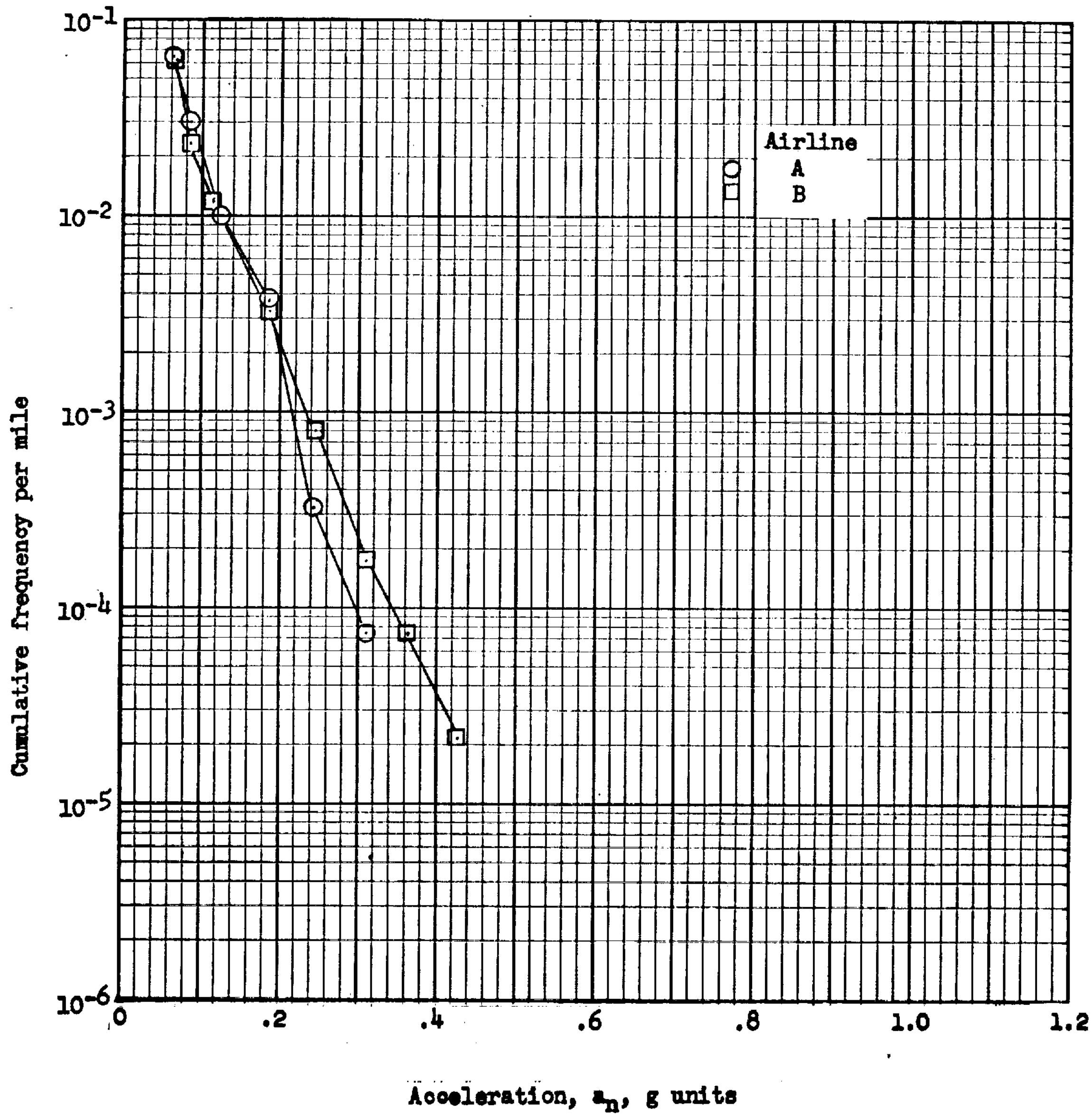
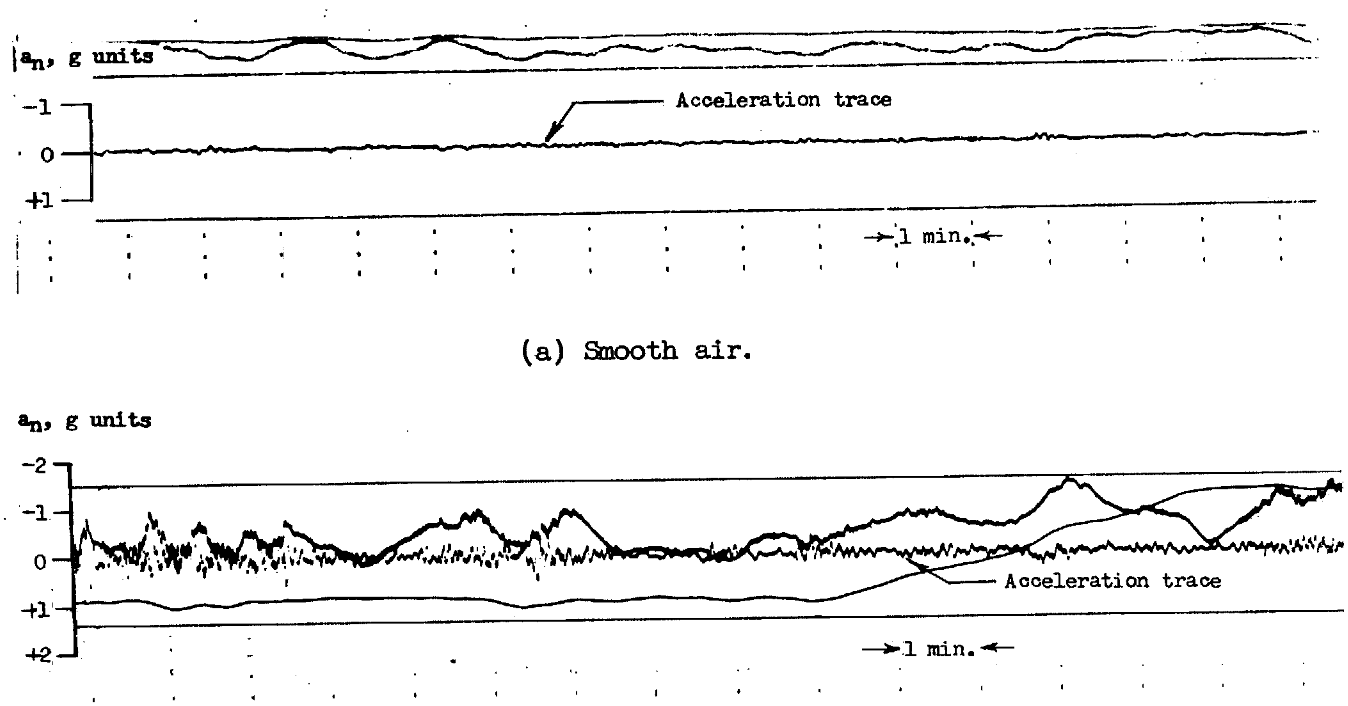


Figure 18.- Estimated frequency per mile of oscillatory accelerations.



(a) Smooth air.

(b) Rough air.

Figure 19.- Examples of oscillatory accelerations occurring after March 27, 1960.

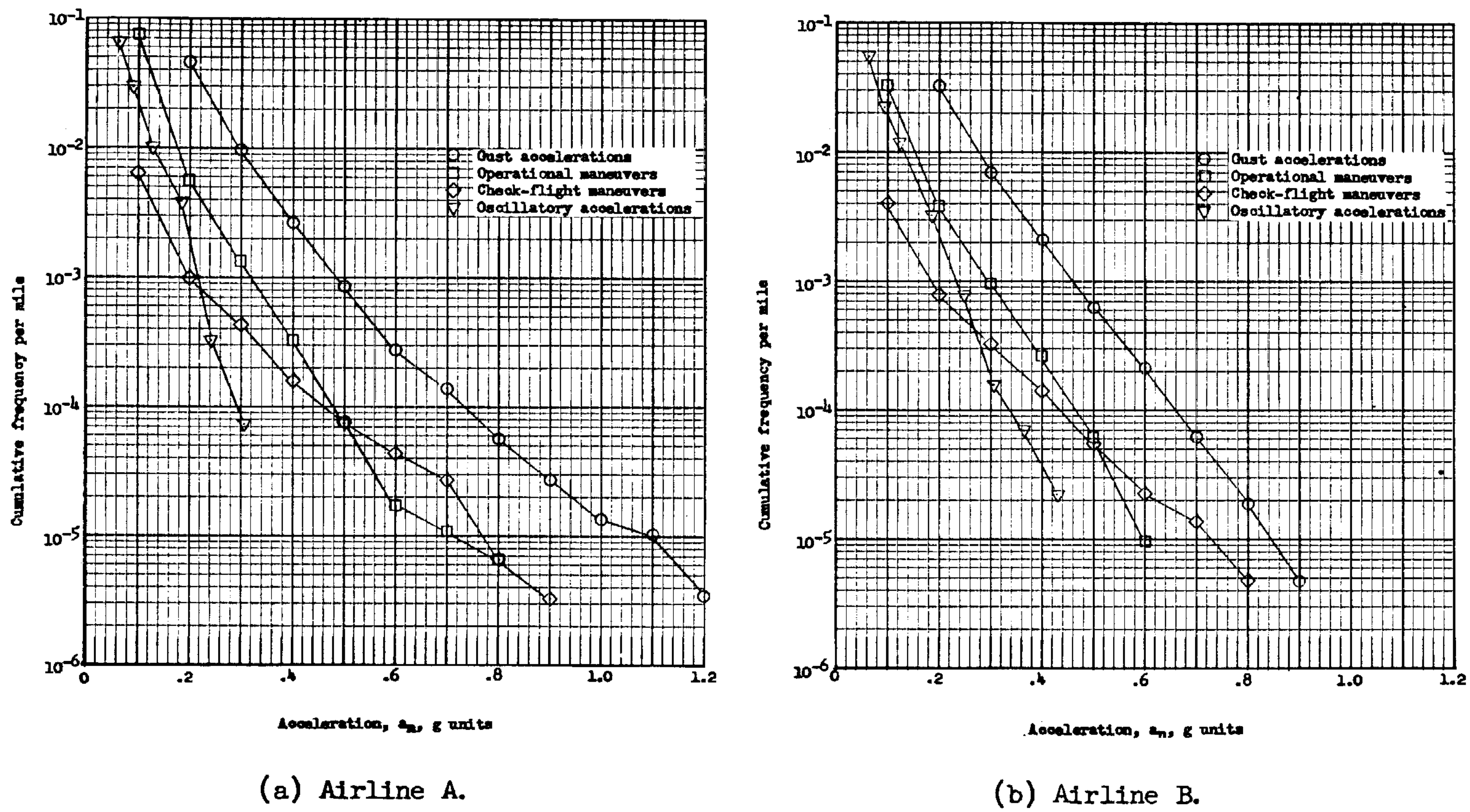


Figure 20.- Comparison of in-flight accelerations experienced per mile of flight.

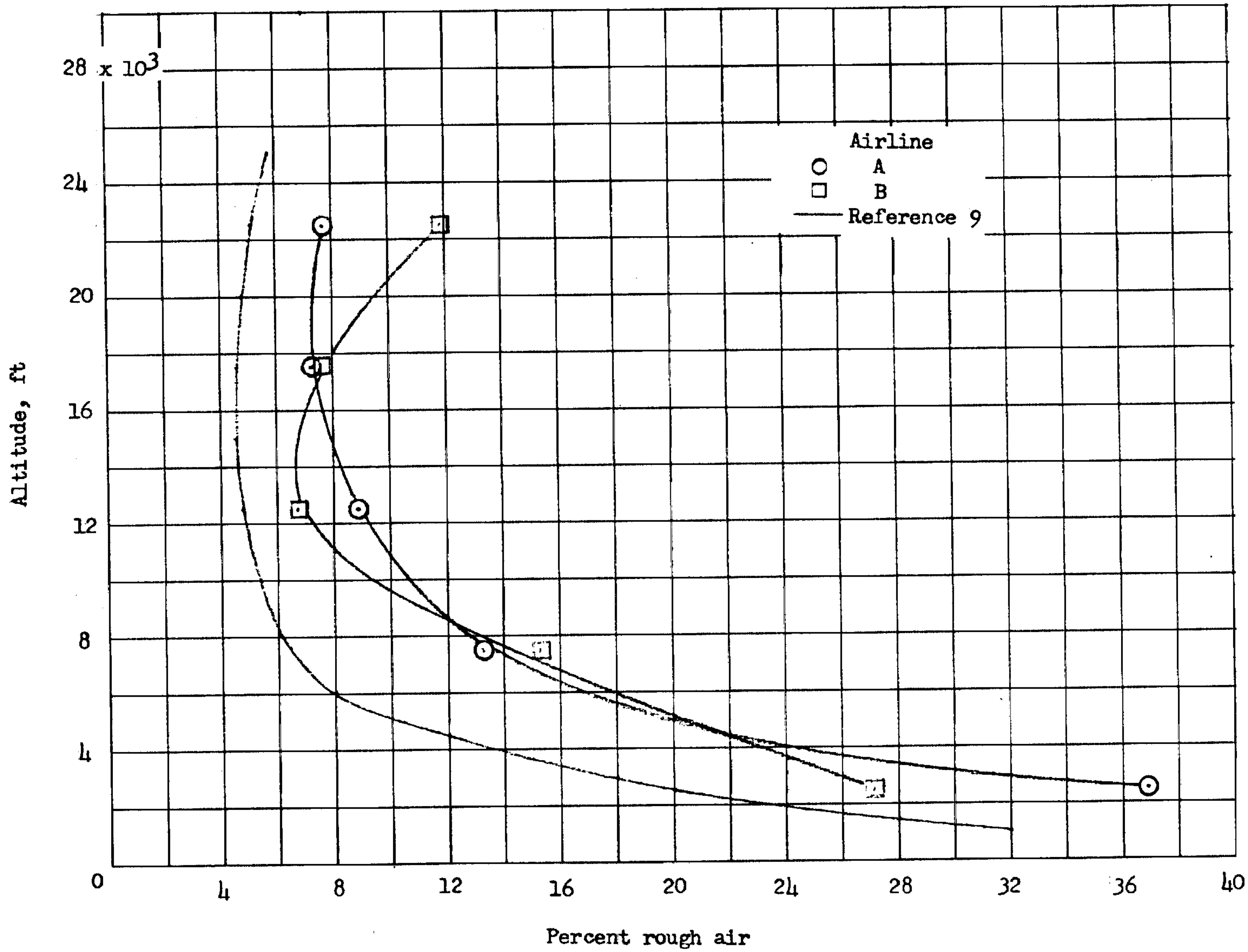


Figure 21. - Variation in percentage of rough air with altitude.

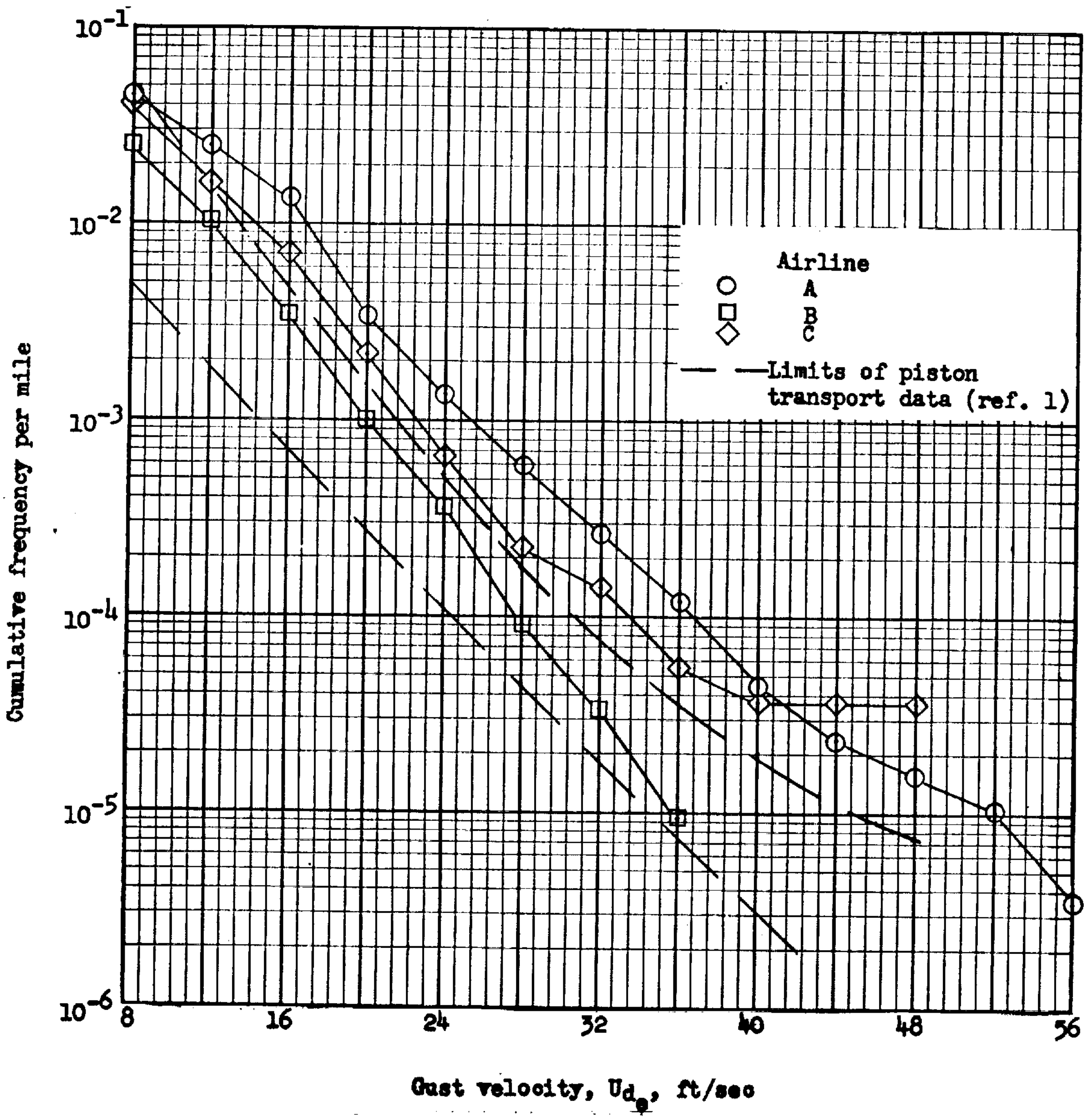
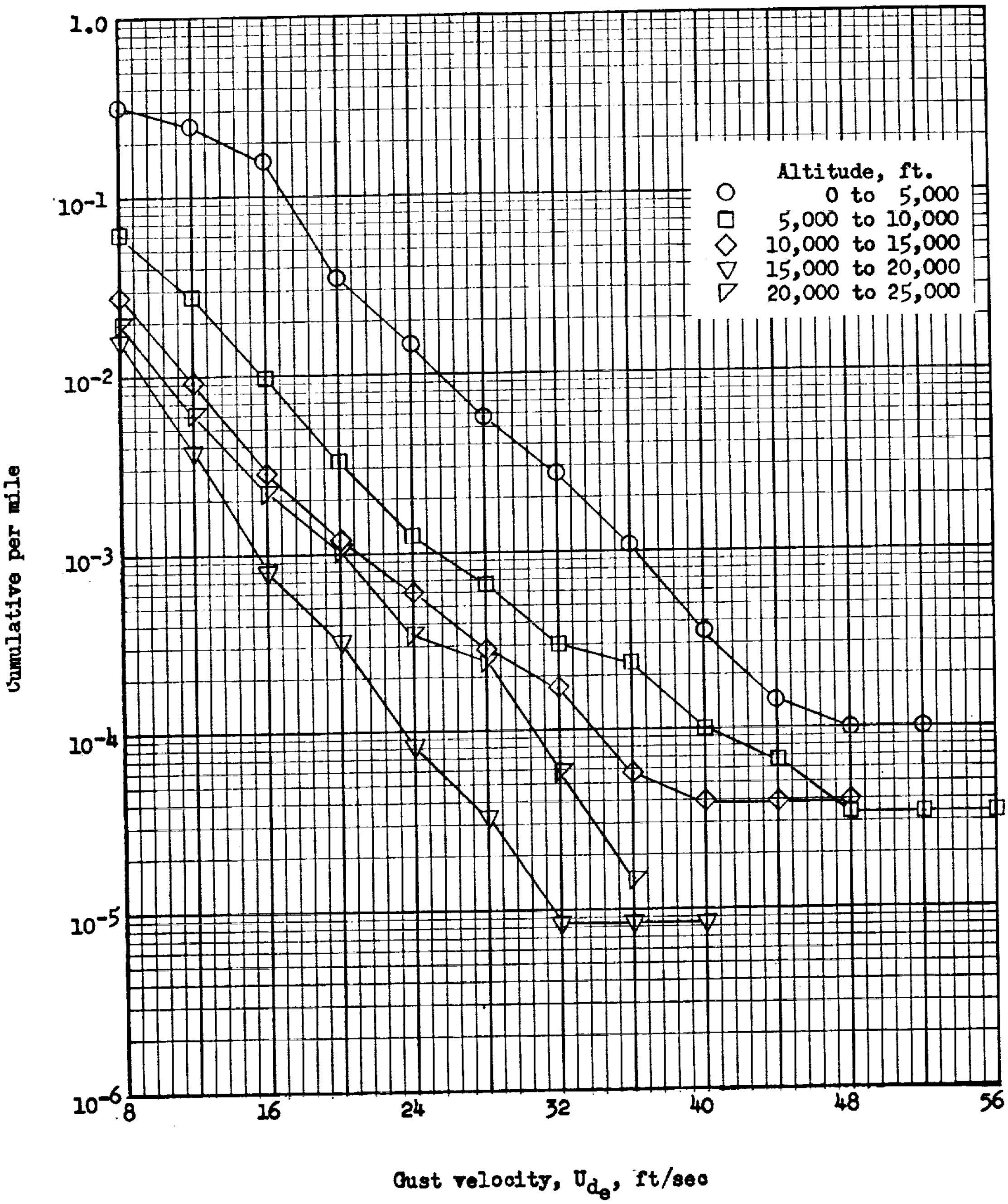
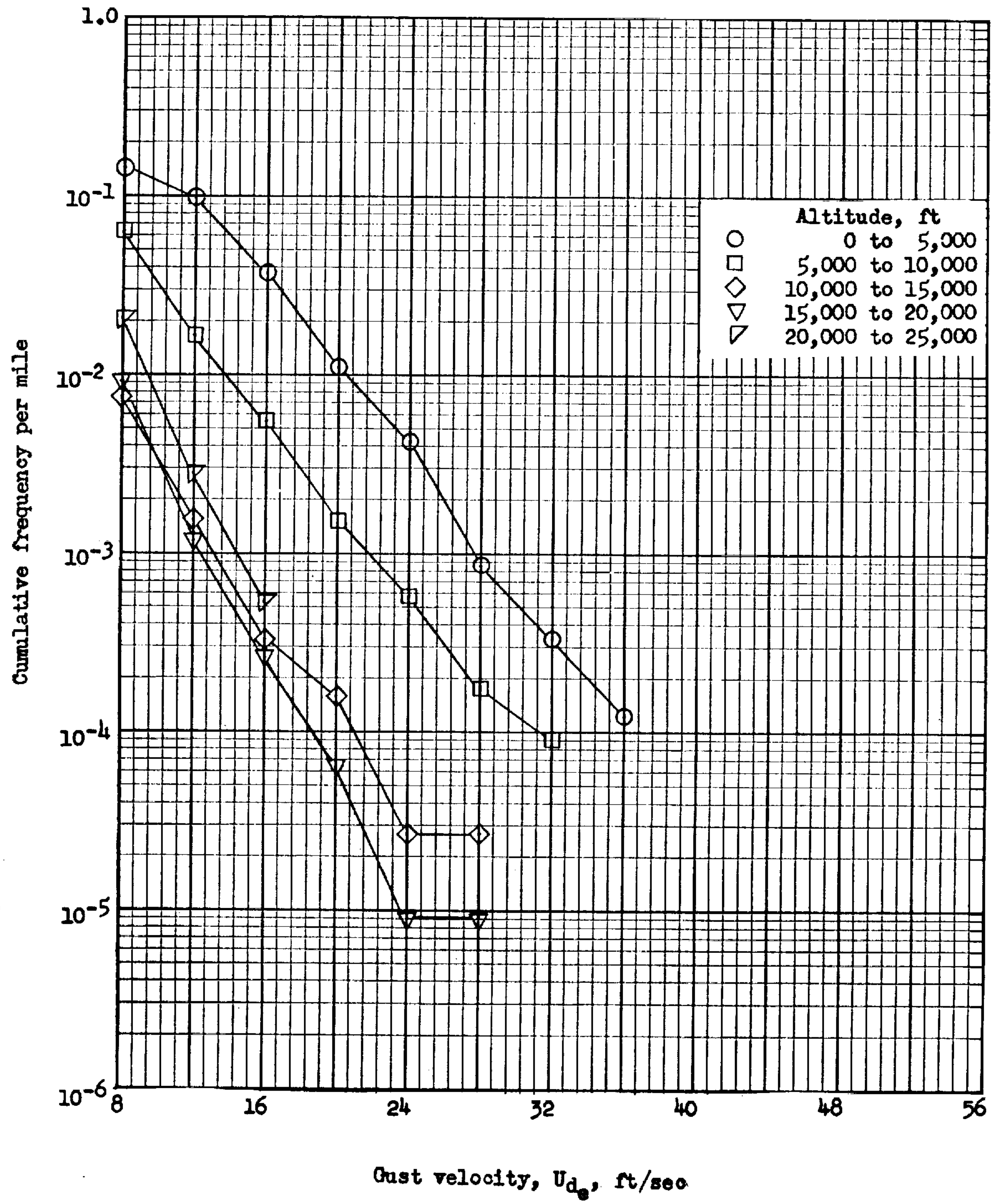


Figure 22.- Comparison of derived gust-velocity histories.



(a) Airline A.

Figure 23. - Distribution of derived gust velocities by altitude brackets as a function of the cumulative frequency per mile.



(b) Airline B.

Figure 23.- Concluded.

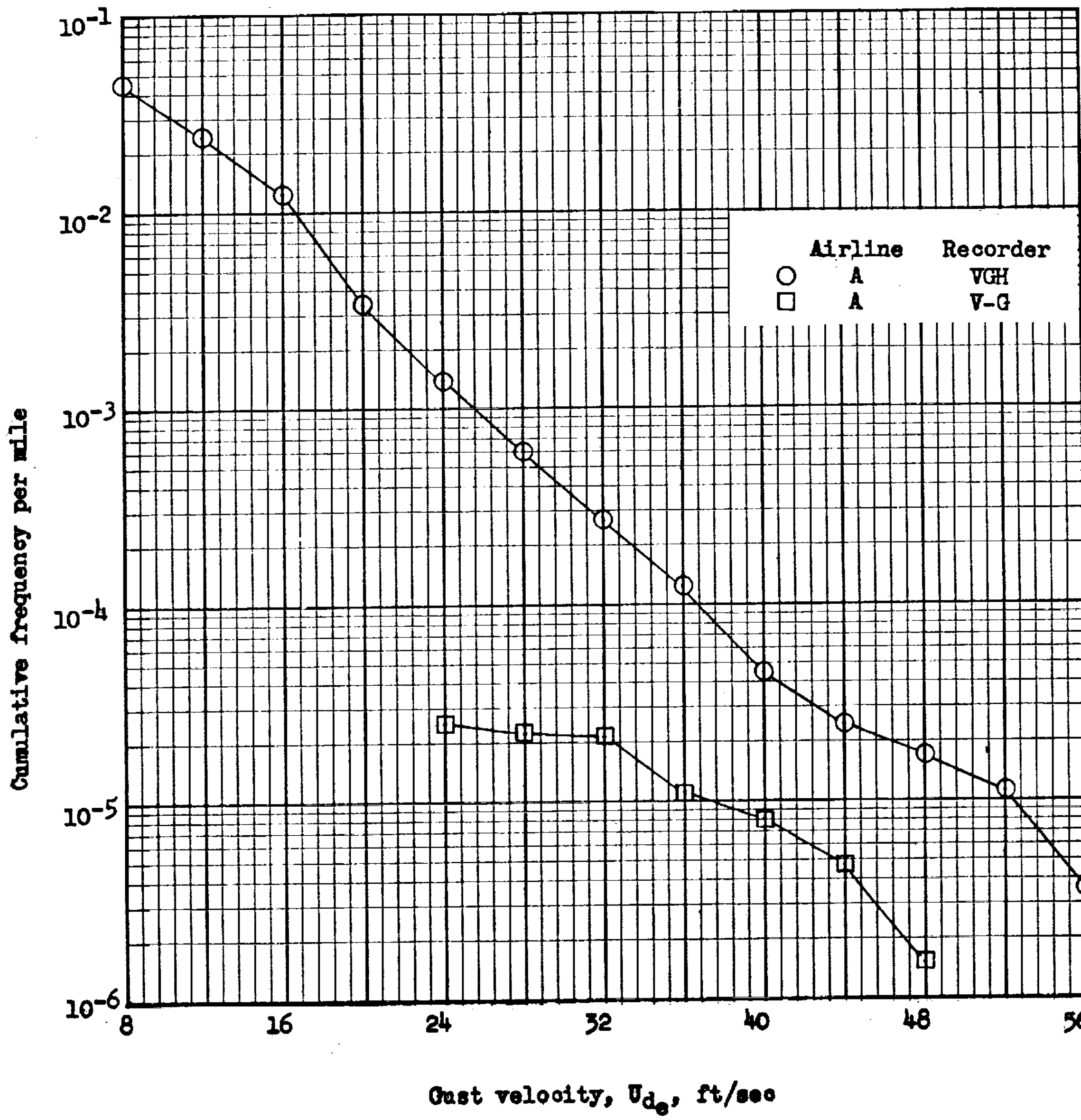
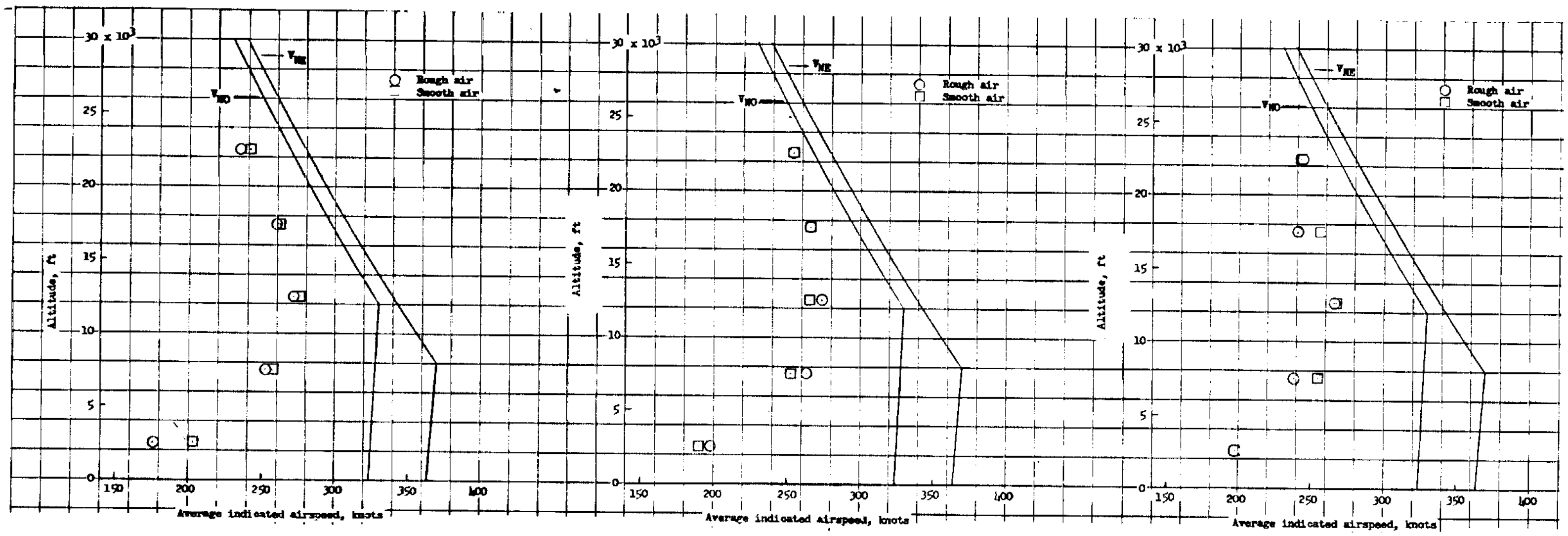


Figure 24.- Comparison of gust velocities obtained from VGH and V-G data.



(a) Airline A.

(b) Airline B.

(c) Airline C.

Figure 25.- Average indicated airspeeds in smooth and rough air.

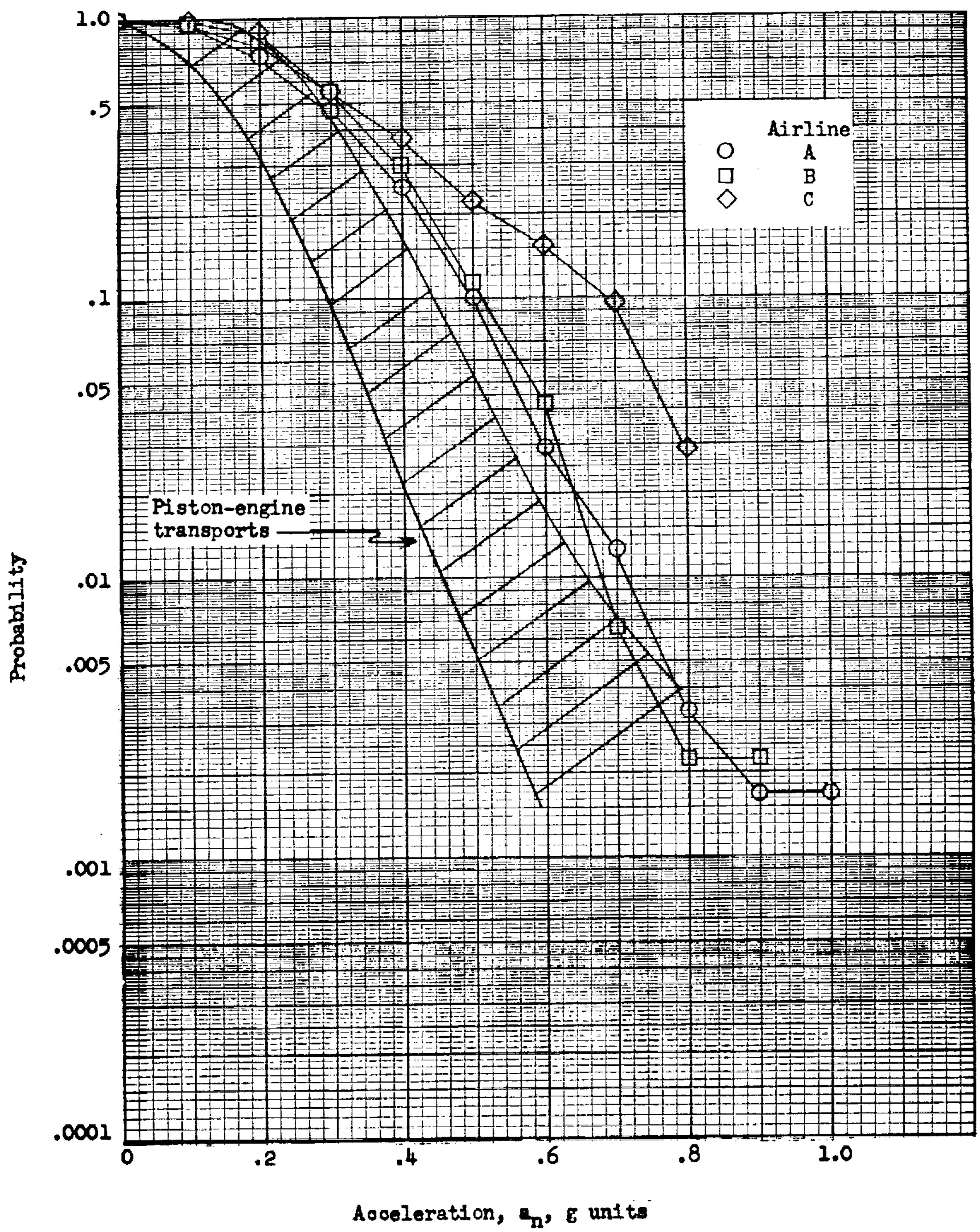


Figure 26.- Probability curves of initial impact positive landing accelerations experienced by the test airplane and four piston-engine transports.

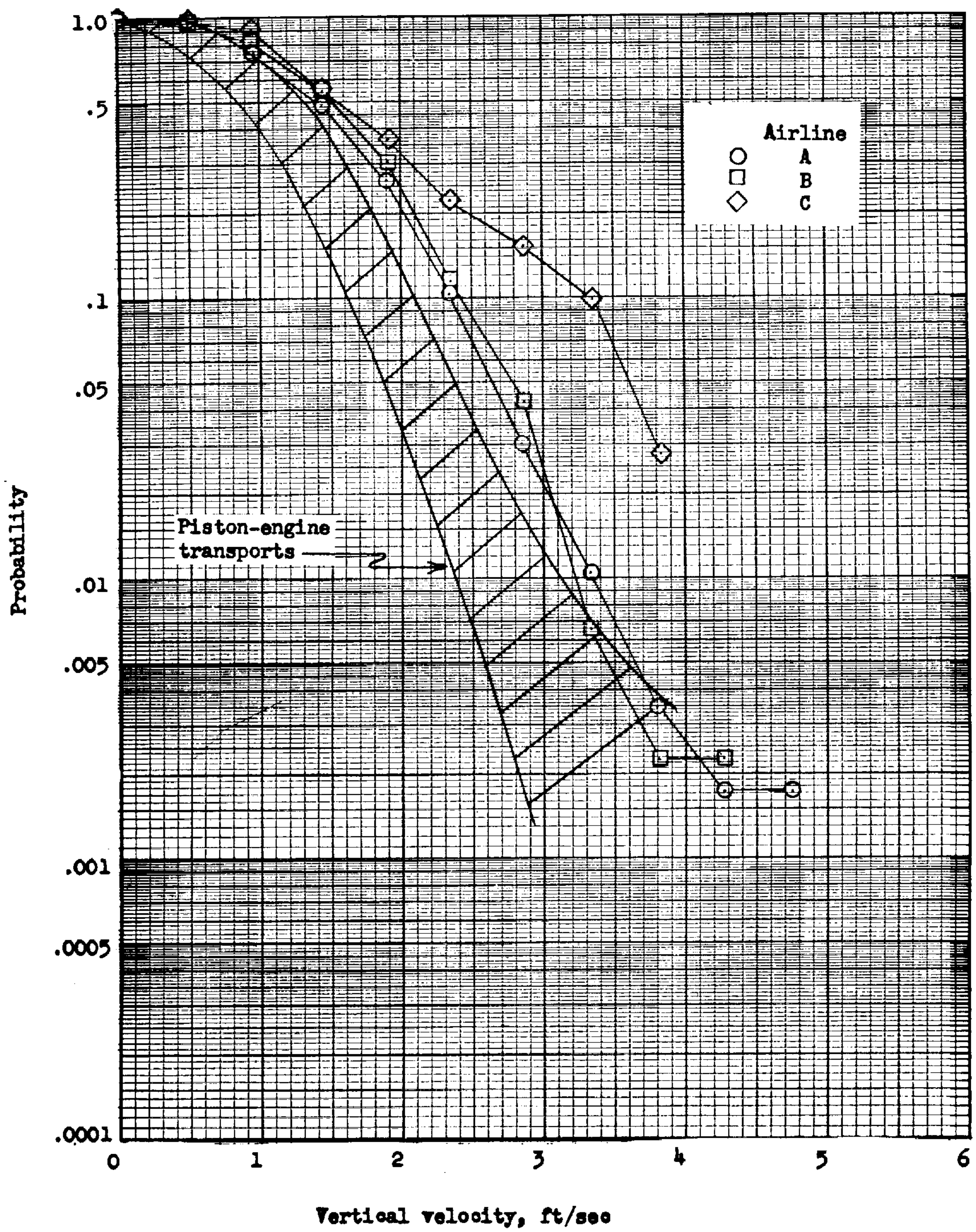


Figure 27.- Probability curves of vertical velocity of landing impact for the test airplane and four piston-engine transports.